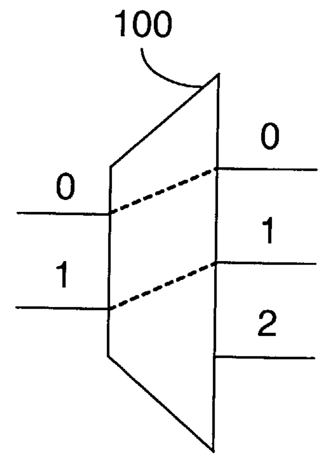


FIG. 1A

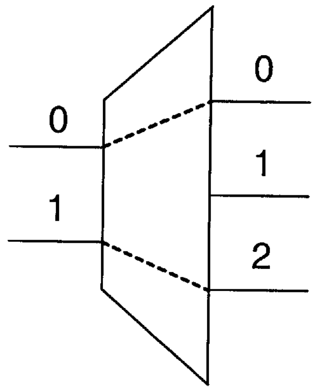


FIG. 1B

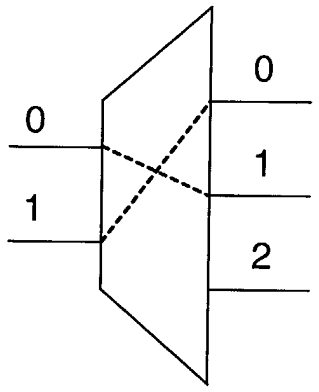


FIG. 1C

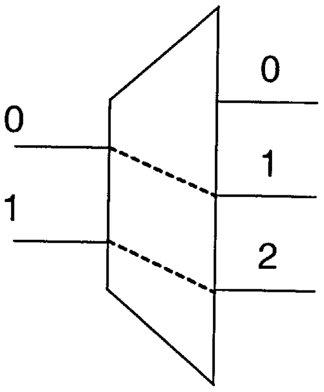


FIG. 1D

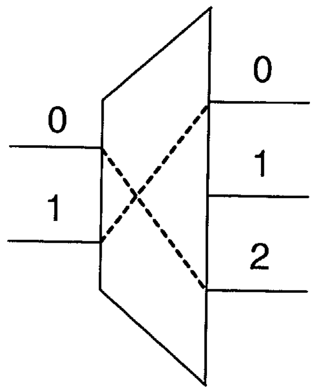


FIG. 1E

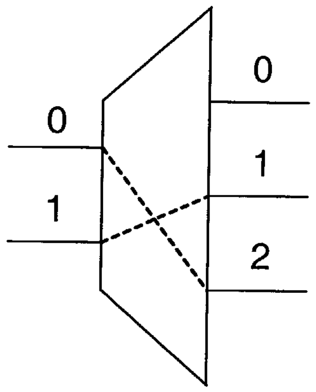


FIG. 1F

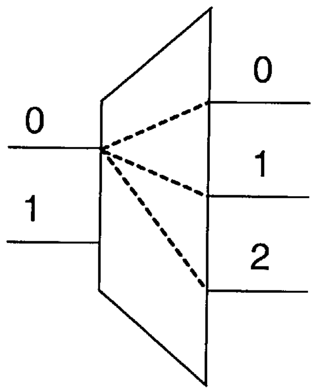


FIG. 1G

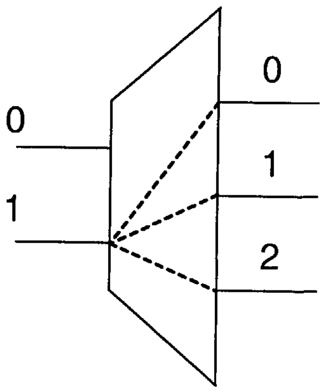


FIG. 1H

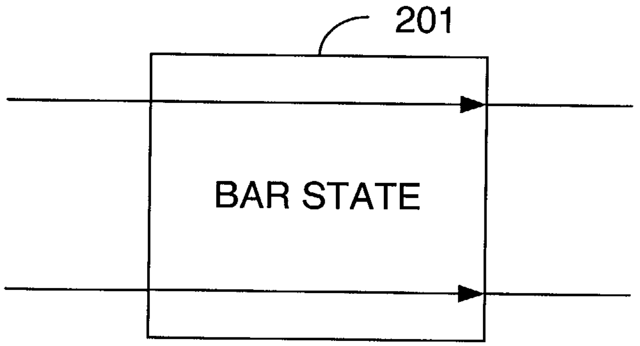


FIG. 2A

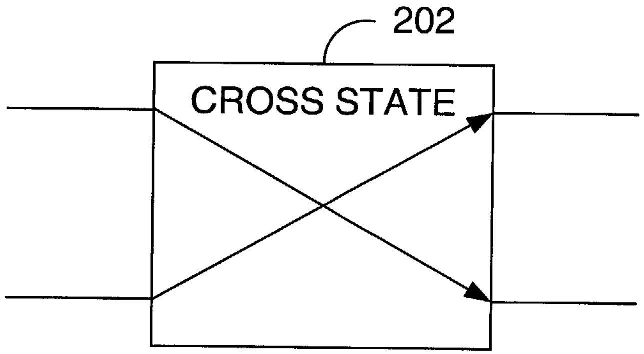


FIG. 2B

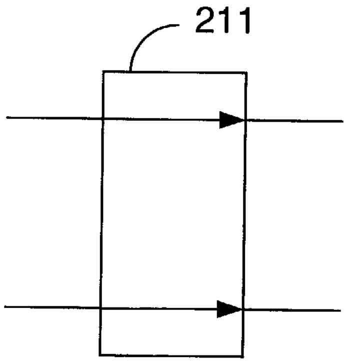


FIG. 2C

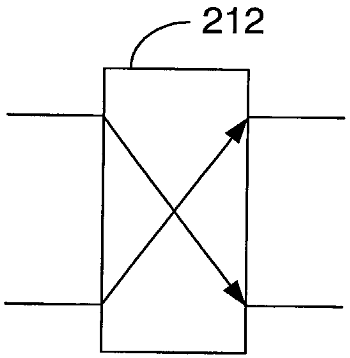


FIG. 2D

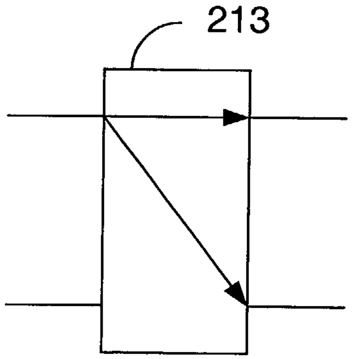


FIG. 2E

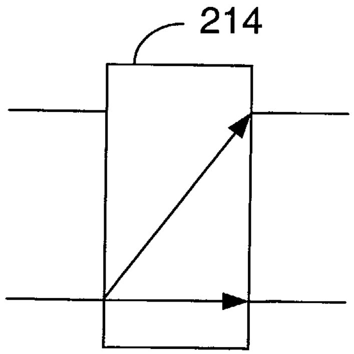


FIG. 2F

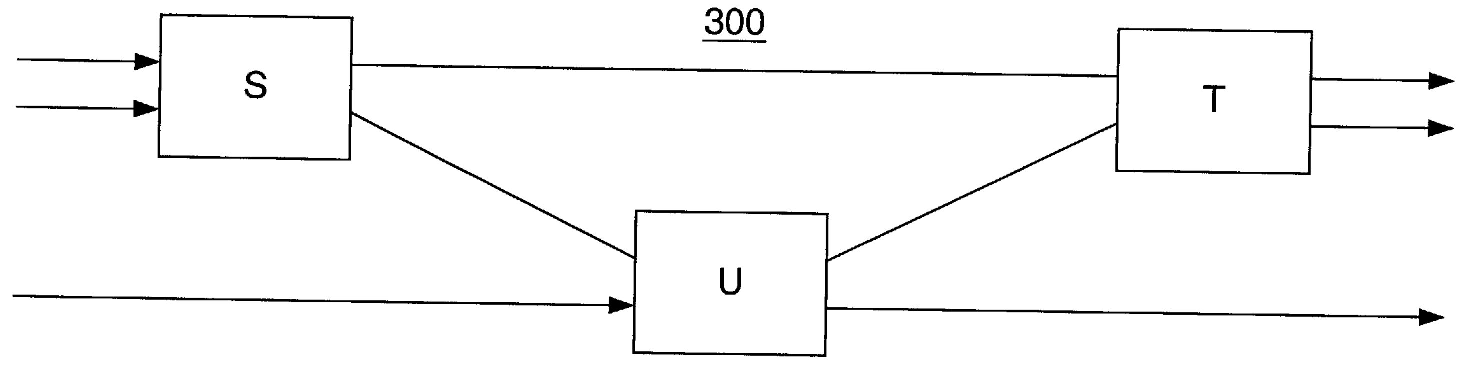


FIG. 3A

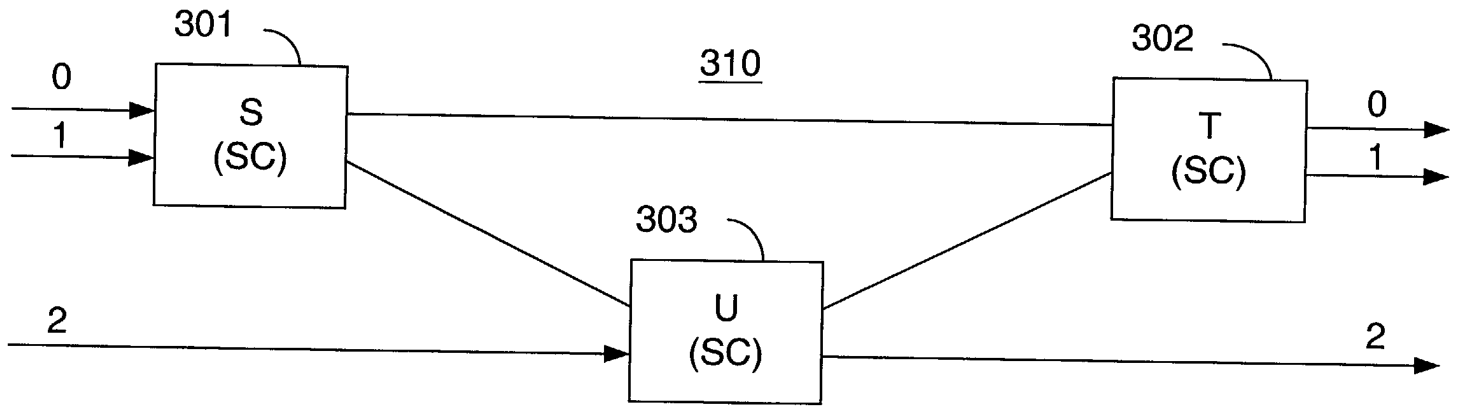


FIG. 3B

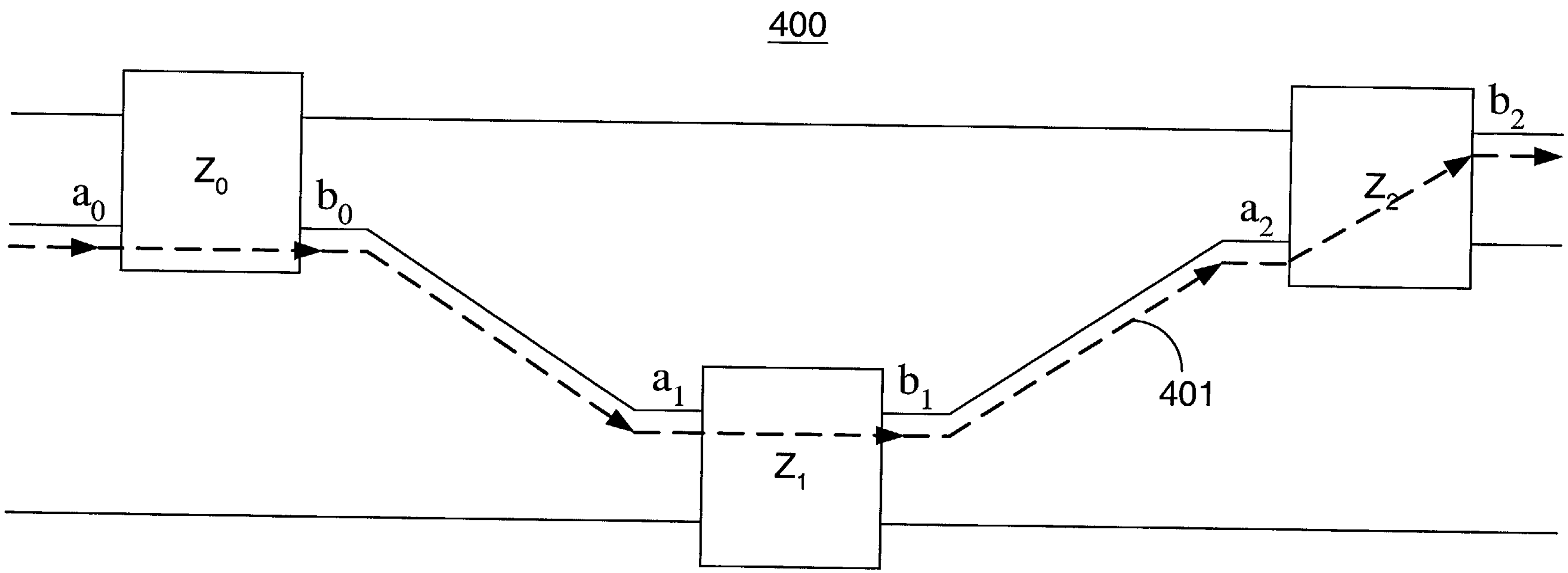


FIG. 4

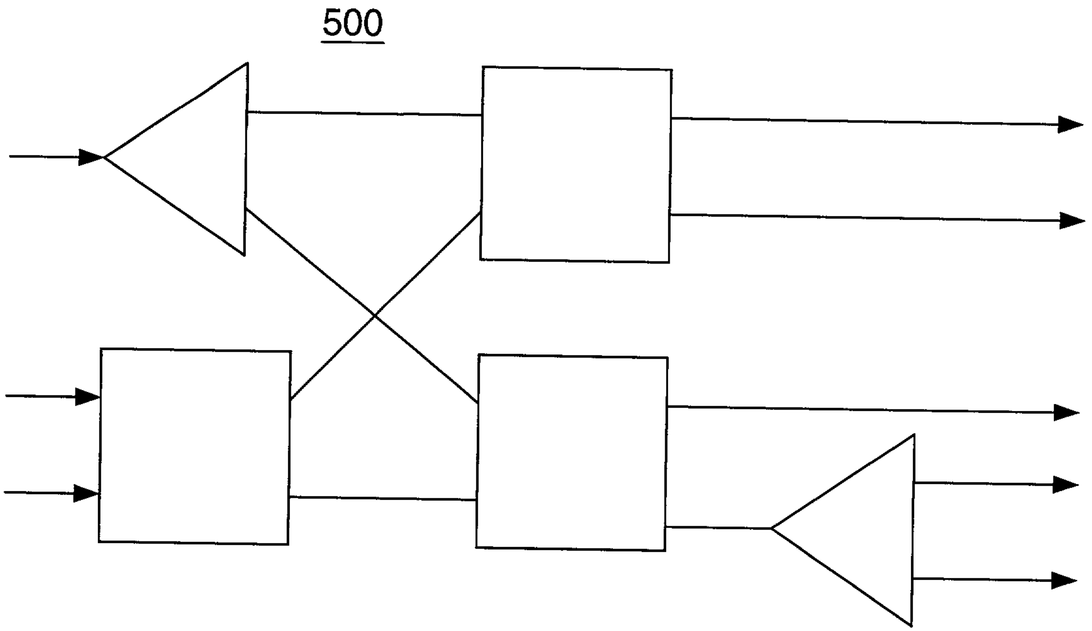


FIG. 5A

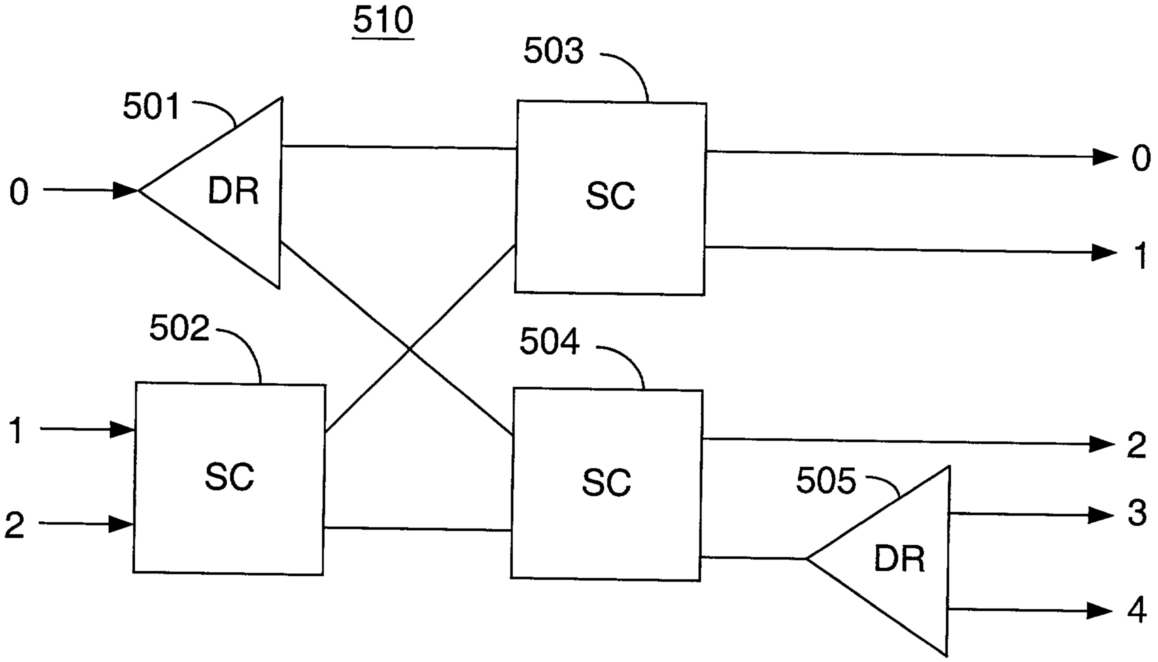


FIG. 5B

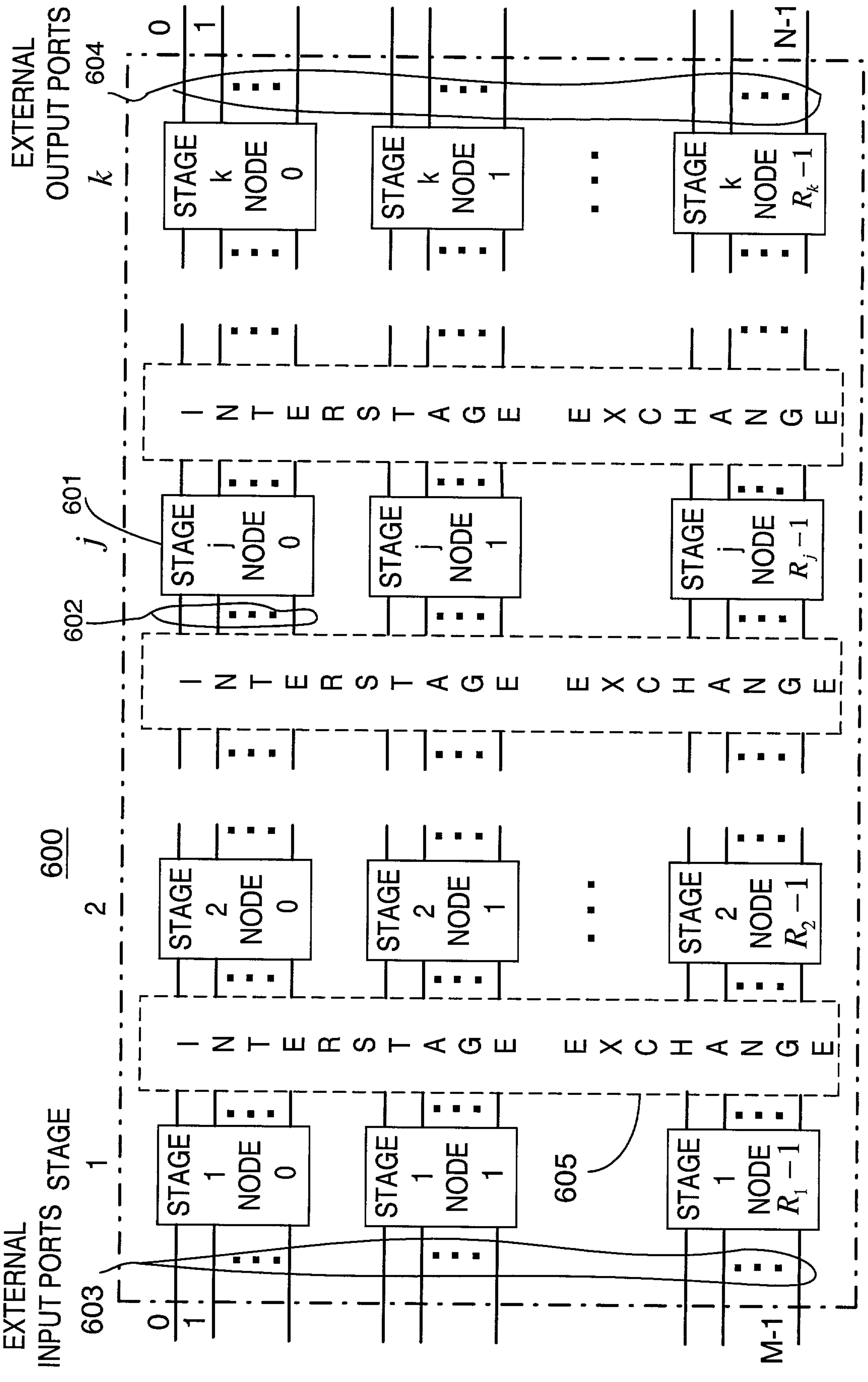

600
EXTERNAL INPUT PORTS
603
0
1
M-1
STAGE 1
STAGE 1 NODE 0
STAGE 1 NODE 1
STAGE 1 NODE R_1-1
605
INTERSTAGE EXCHANGE
2
STAGE 2 NODE 0
STAGE 2 NODE 1
STAGE 2 NODE R_2-1
INTERSTAGE EXCHANGE
602
j
601
STAGE j NODE 0
STAGE j NODE 1
STAGE j NODE R_j-1
INTERSTAGE EXCHANGE
k
STAGE k NODE 0
STAGE k NODE 1
STAGE k NODE R_k-1
604
EXTERNAL OUTPUT PORTS
0
1
N-1

FIG. 6A

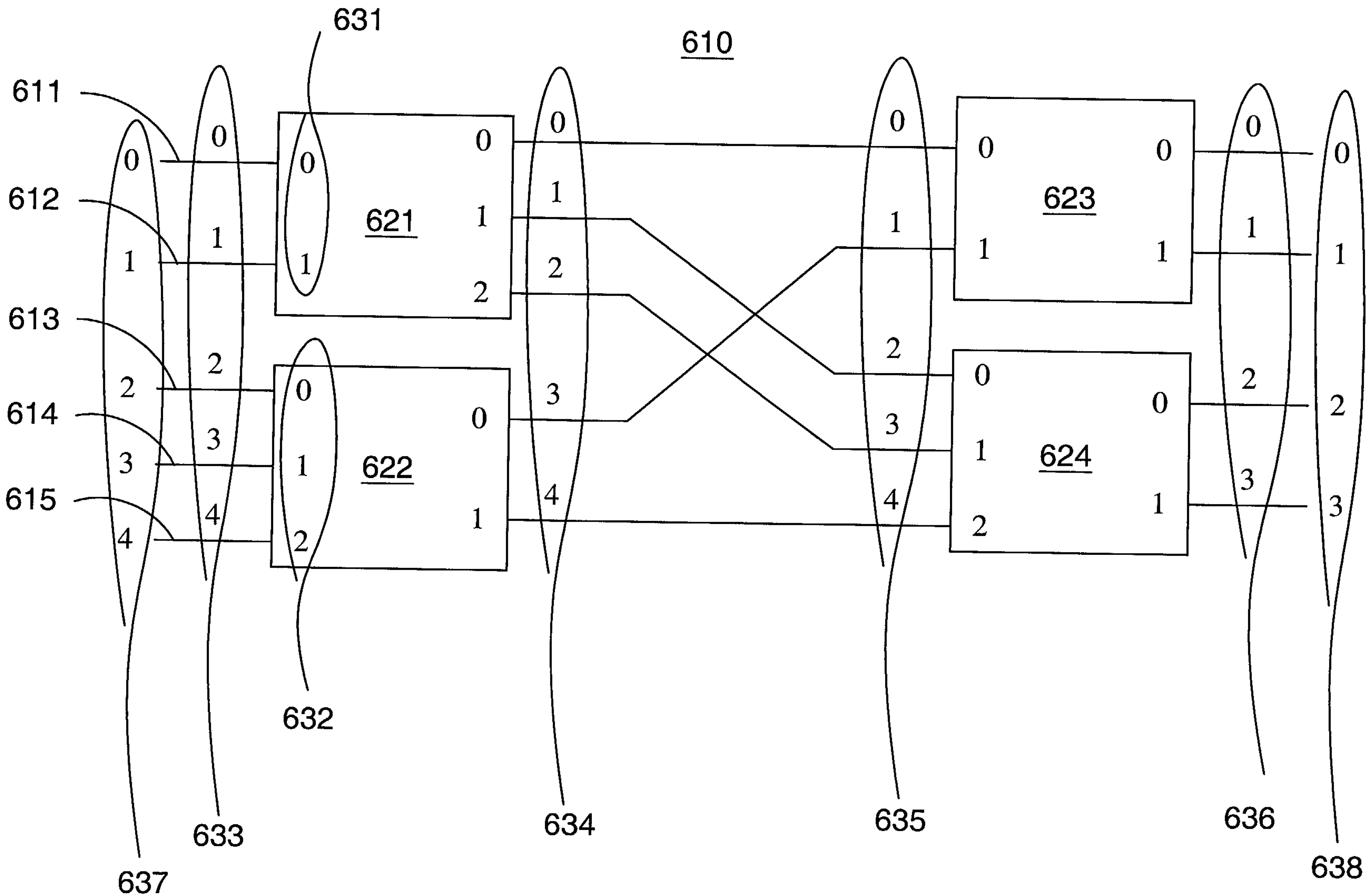

631
610
611
612
613
614
615
621
622
623
624
0
1
2
3
4
632
637
633
634
635
636
638

FIG. 6B

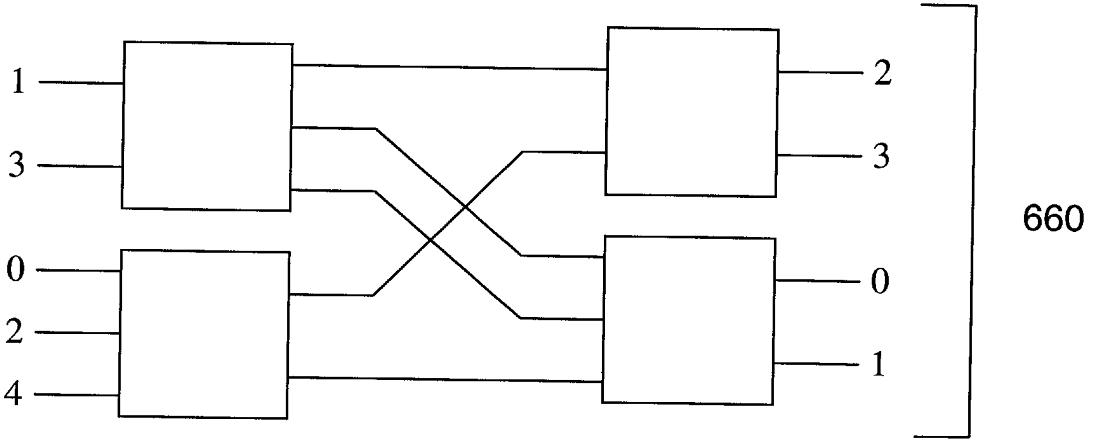

1
3
0
2
4
2
3
0
1
660

FIG. 6C

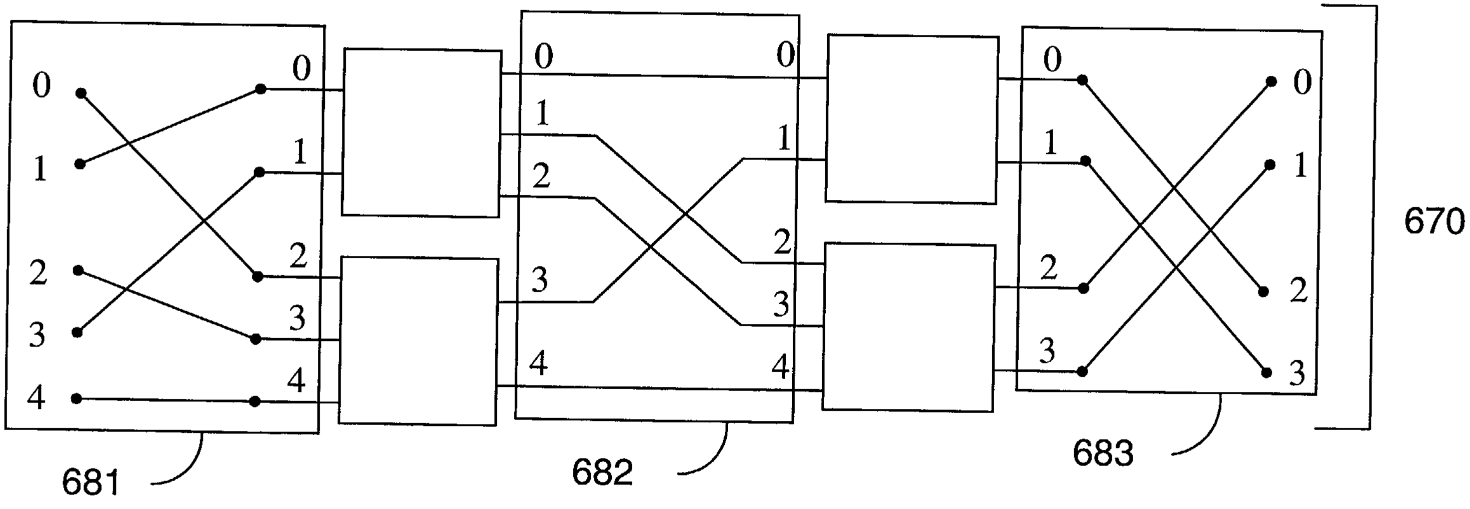

0
1
2
3
4
0
1
2
3
4
0
1
2
3
4
0
1
2
3
4
0
1
2
3
0
1
2
3
670
681
682
683

FIG. 6D

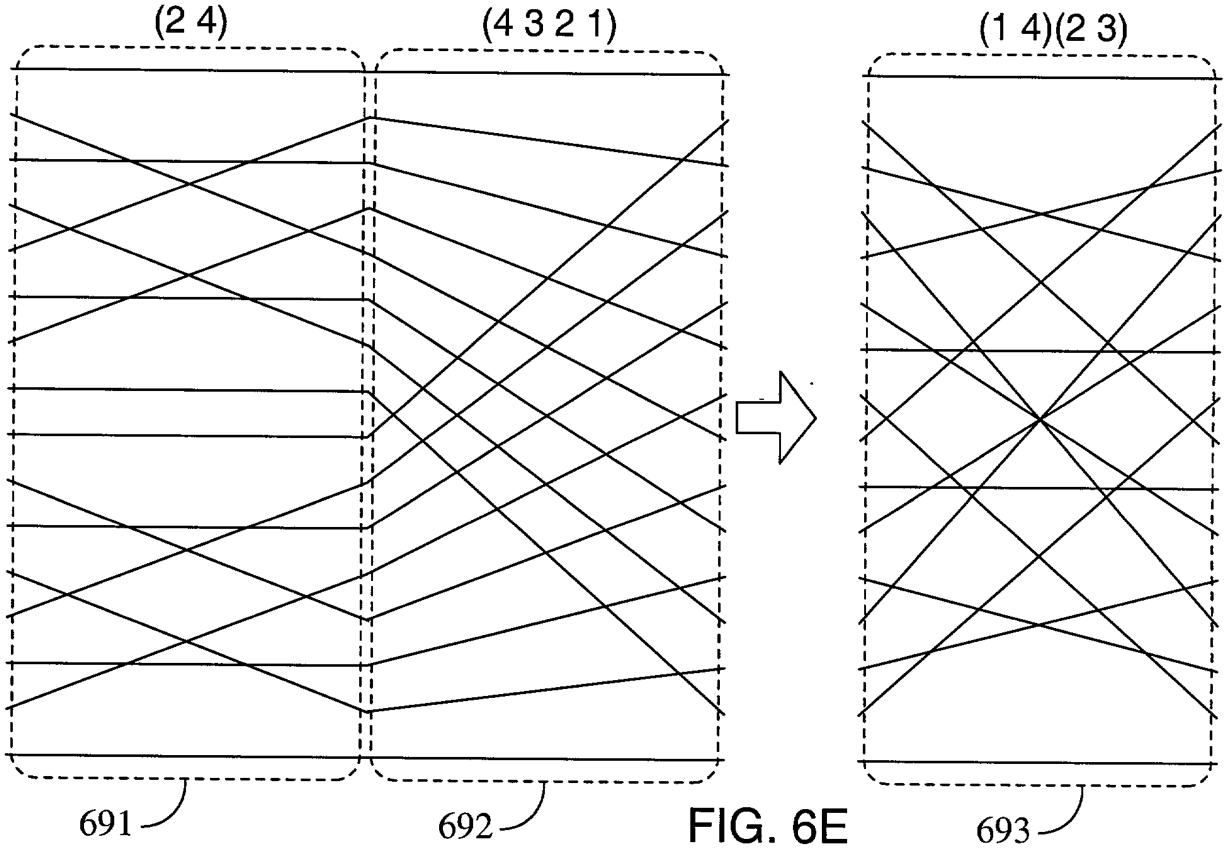


FIG. 6E

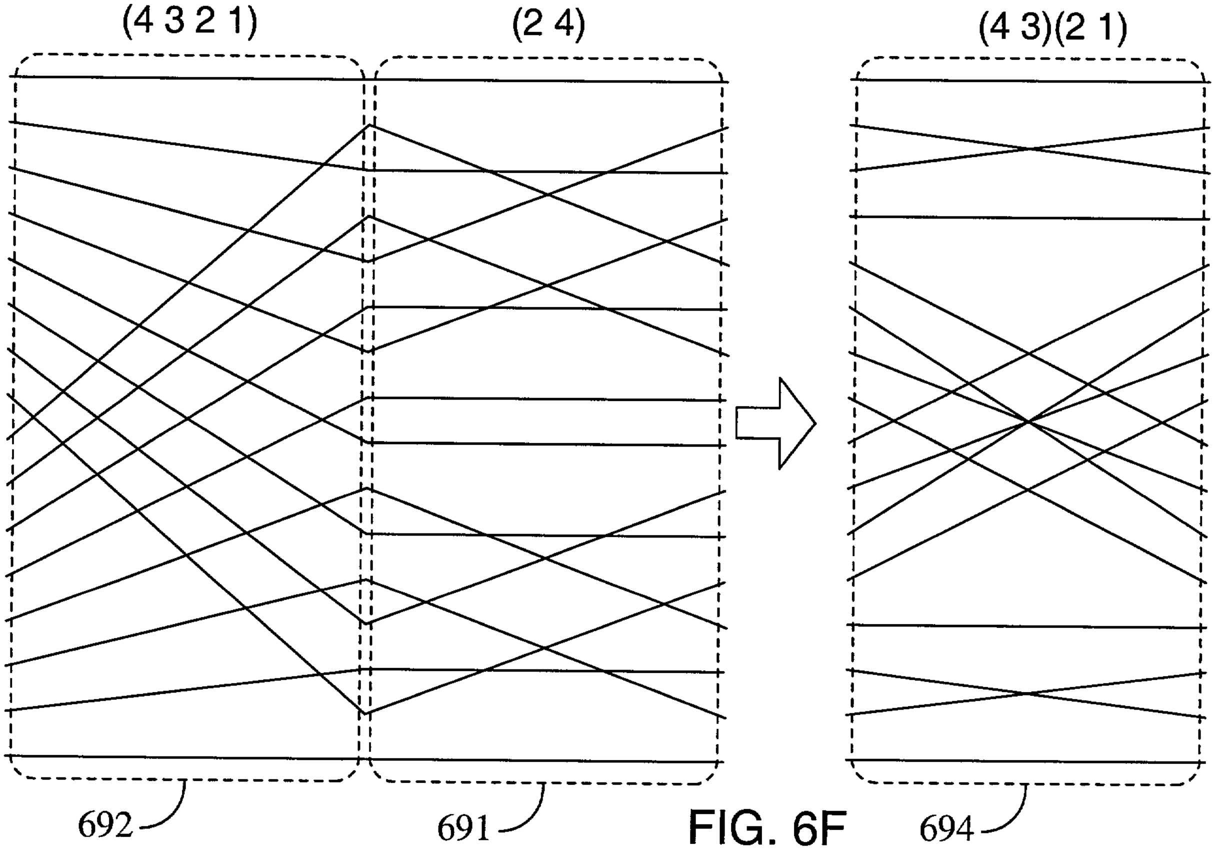


FIG. 6F

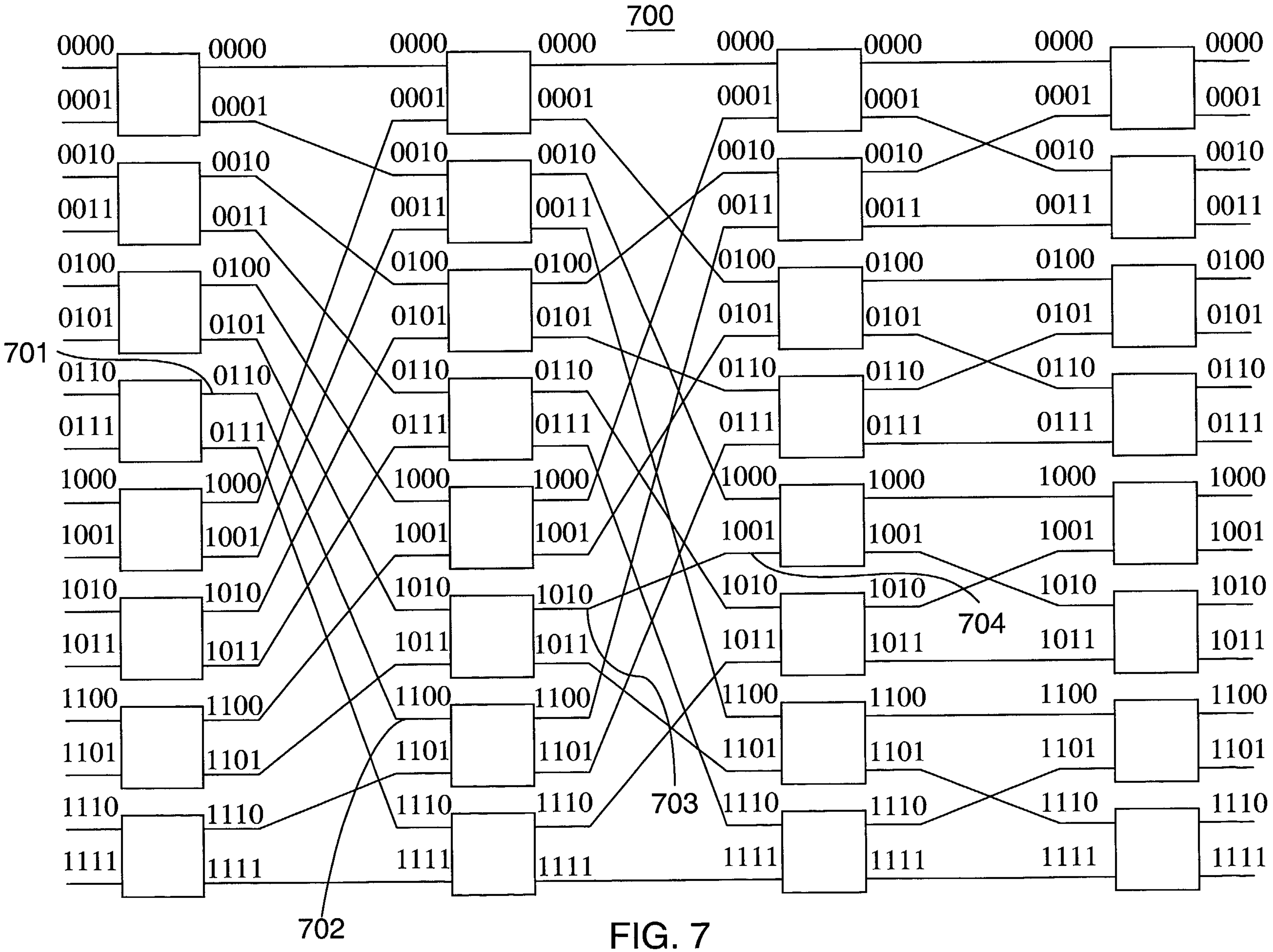

700
701
702
703
704
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111

FIG. 7

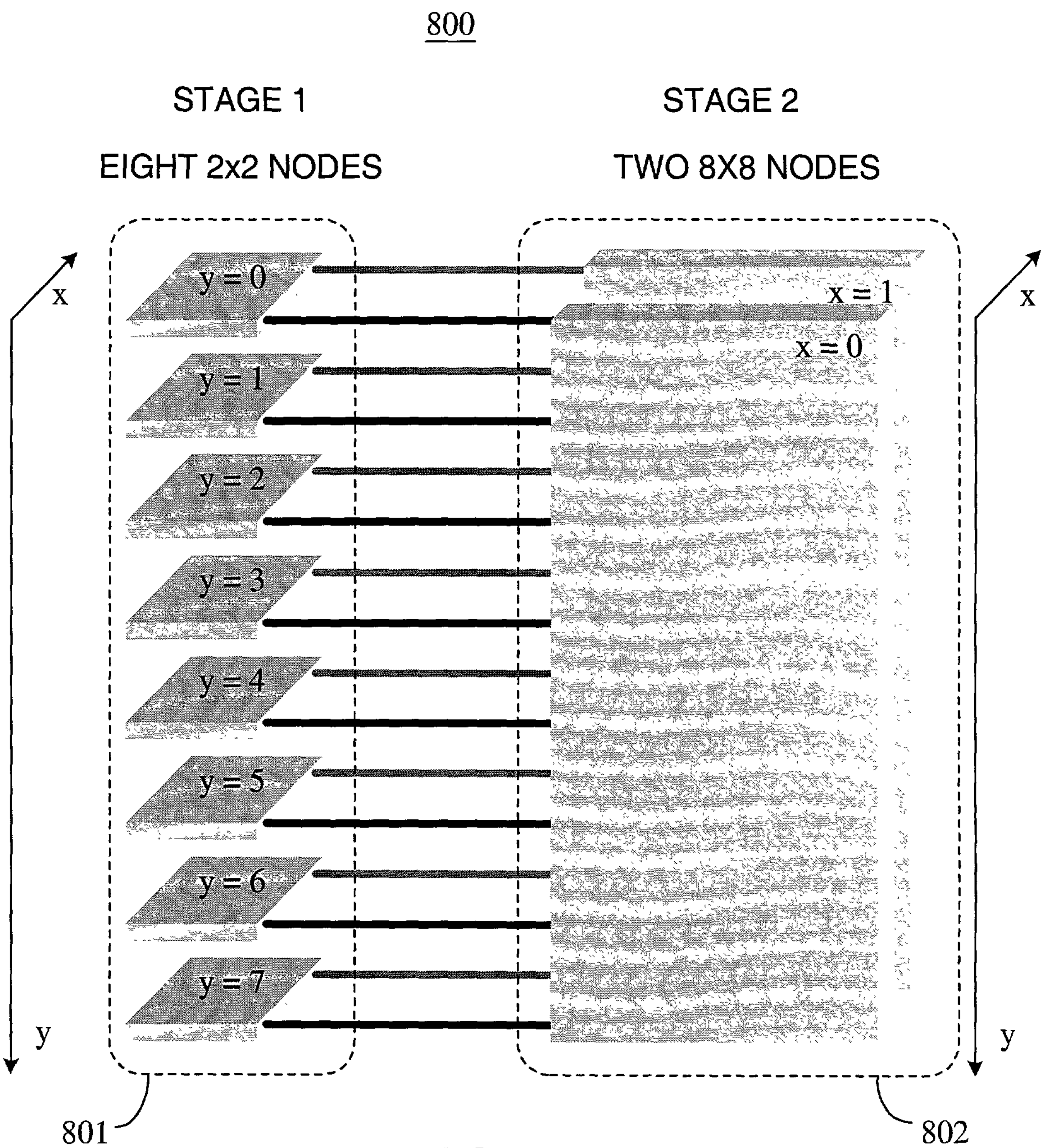
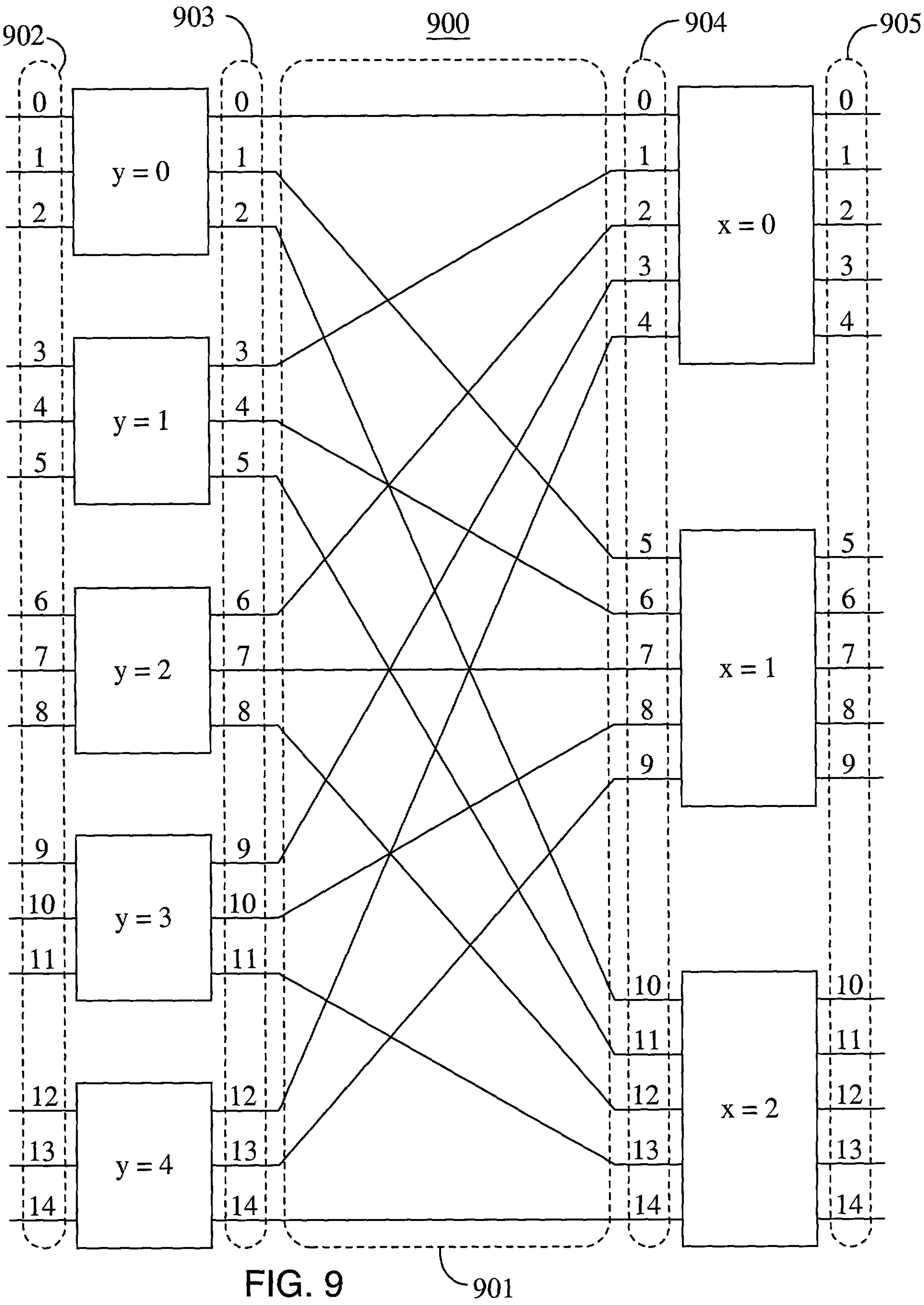

800
STAGE 1
EIGHT 2x2 NODES
STAGE 2
TWO 8X8 NODES
x
y
y = 0
y = 1
y = 2
y = 3
y = 4
y = 5
y = 6
y = 7
x = 1
x = 0
x
y
801
802

FIG. 8



902
903
900
904
905
y = 0
y = 1
y = 2
y = 3
y = 4
x = 0
x = 1
x = 2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
901

FIG. 9

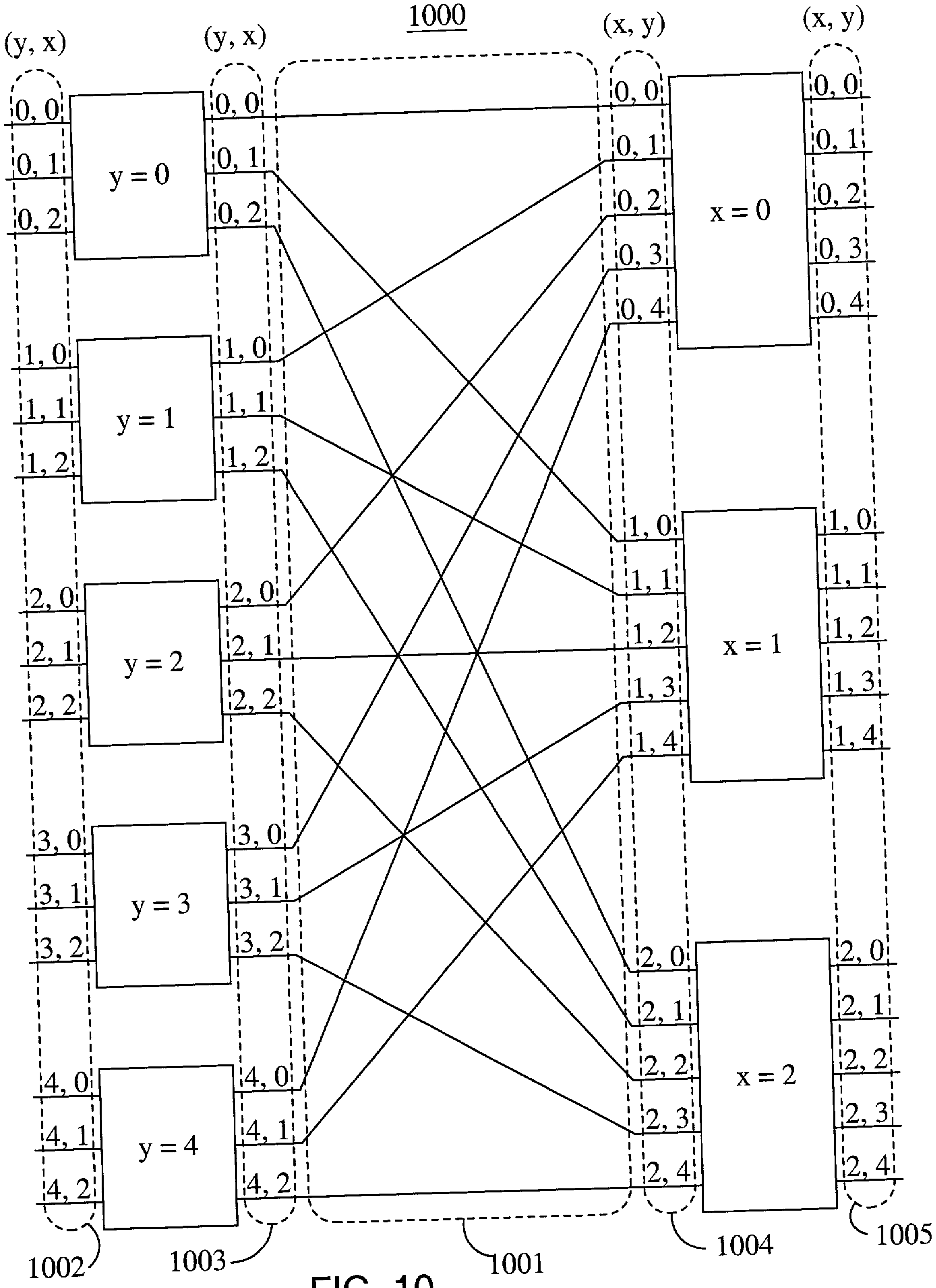

1000
(y, x)
(y, x)
(x, y)
(x, y)
0, 0
0, 1
0, 2
y = 0
1, 0
1, 1
1, 2
y = 1
2, 0
2, 1
2, 2
y = 2
3, 0
3, 1
3, 2
y = 3
4, 0
4, 1
4, 2
y = 4
0, 0
0, 1
0, 2
0, 3
0, 4
x = 0
1, 0
1, 1
1, 2
1, 3
1, 4
x = 1
2, 0
2, 1
2, 2
2, 3
2, 4
x = 2
1002
1003
1001
1004
1005

FIG. 10

1100

$$\begin{tikzcd}
(y, x) \arrow[r, "\text{STAGE-1 SWITCHING}"] & (y, x') \arrow[d, "\text{COORDINATE INTERCHANGE}"'] & \\
& (x', y) \arrow[r, "\text{STAGE-2 SWITCHING}"] & (x', y') \arrow[d, "\text{INVERSE COORDINATE INTERCHANGE}"'] \\
& & (y', x')
\end{tikzcd}$$

FIG. 11A

1110

$$\begin{tikzcd}
(x, y) \arrow[d, "\text{INVERSE COORDINATE INTERCHANGE}"] & & \\
(y, x) \arrow[r, "\text{STAGE-1 SWITCHING}"'] & (y, x') \arrow[d, "\text{COORDINATE INTERCHANGE}"] & \\
& (x', y) \arrow[r, "\text{STAGE-2 SWITCHING}"] & (x', y')
\end{tikzcd}$$

FIG. 11B

1200

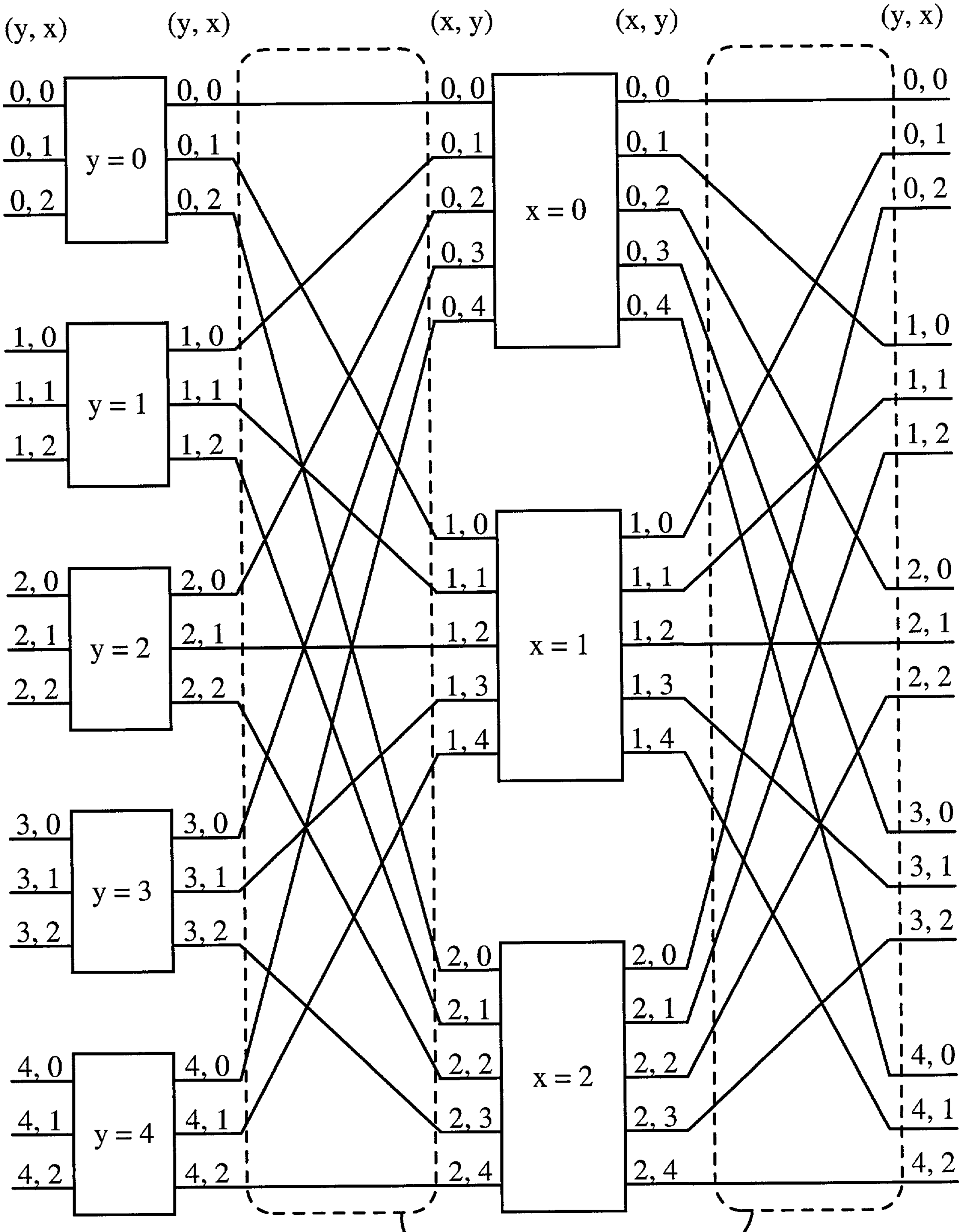

(y, x)
(y, x)
(x, y)
(x, y)
(y, x)
y = 0
y = 1
y = 2
y = 3
y = 4
x = 0
x = 1
x = 2
0, 0
0, 1
0, 2
1, 0
1, 1
1, 2
2, 0
2, 1
2, 2
3, 0
3, 1
3, 2
4, 0
4, 1
4, 2
0, 3
0, 4
1, 3
1, 4
2, 3
2, 4
1201
1202

FIG. 12

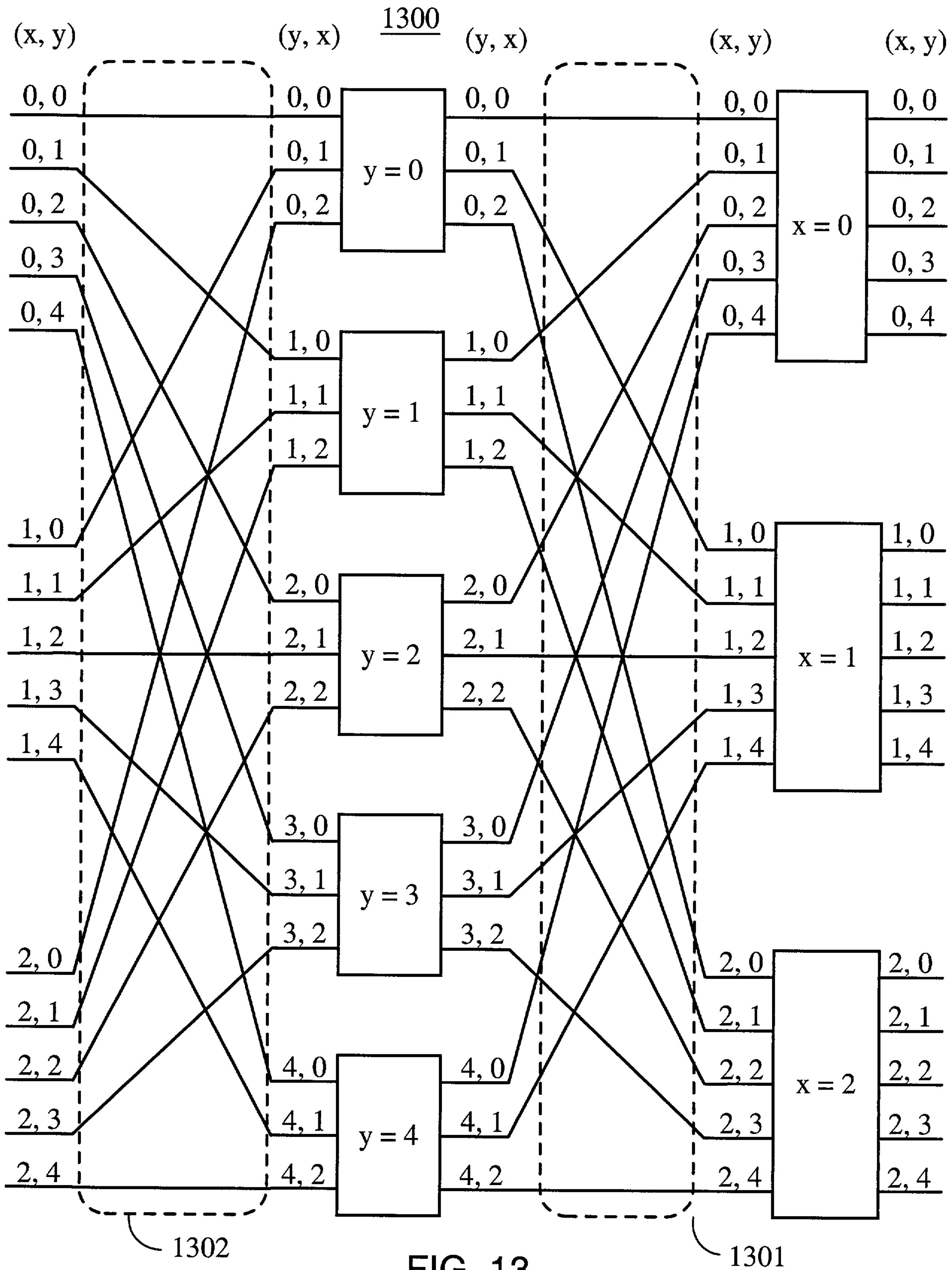

1300
(x, y)
(y, x)
(y, x)
(x, y)
(x, y)
0, 0
0, 1
0, 2
0, 3
0, 4
1, 0
1, 1
1, 2
1, 3
1, 4
2, 0
2, 1
2, 2
2, 3
2, 4
y = 0
y = 1
y = 2
y = 3
y = 4
x = 0
x = 1
x = 2
1302
1301

FIG. 13

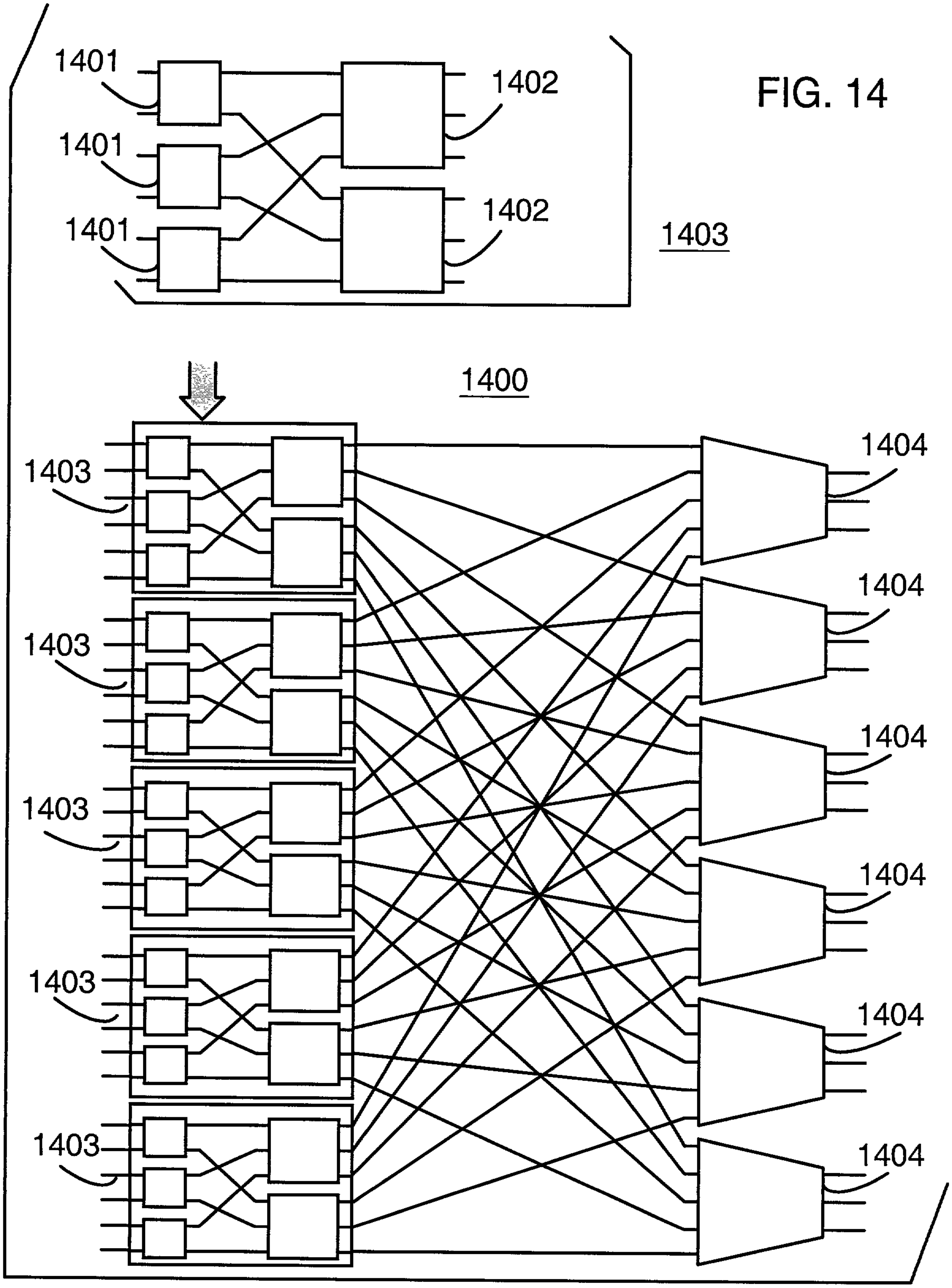

1401
1401
1401
1402
1402
1403
1400
1403
1403
1403
1403
1403
1404
1404
1404
1404
1404
1404

FIG. 14

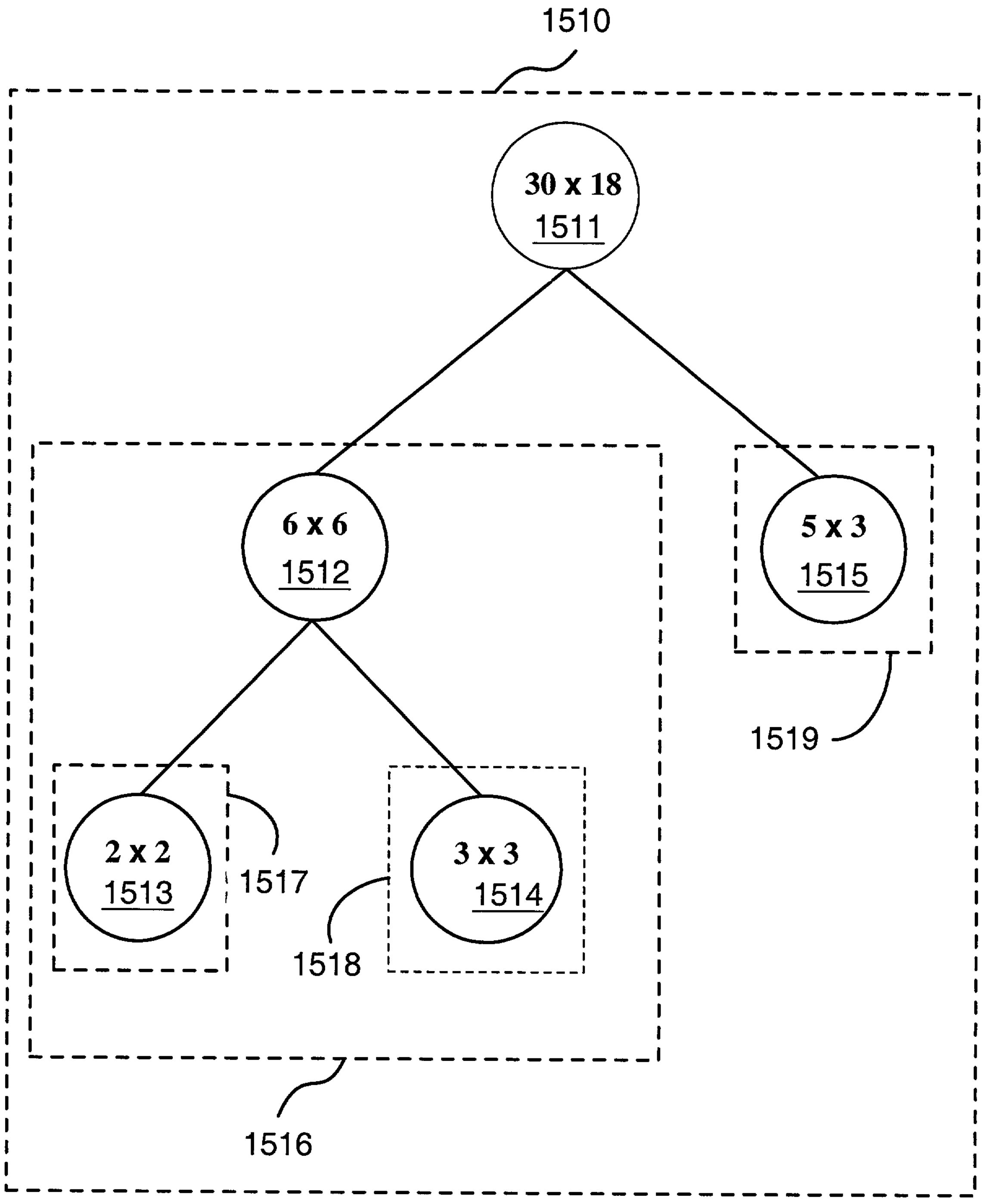

1510
30 x 18
1511
6 x 6
1512
5 x 3
1515
2 x 2
1513
3 x 3
1514
1517
1518
1519
1516

FIG. 15

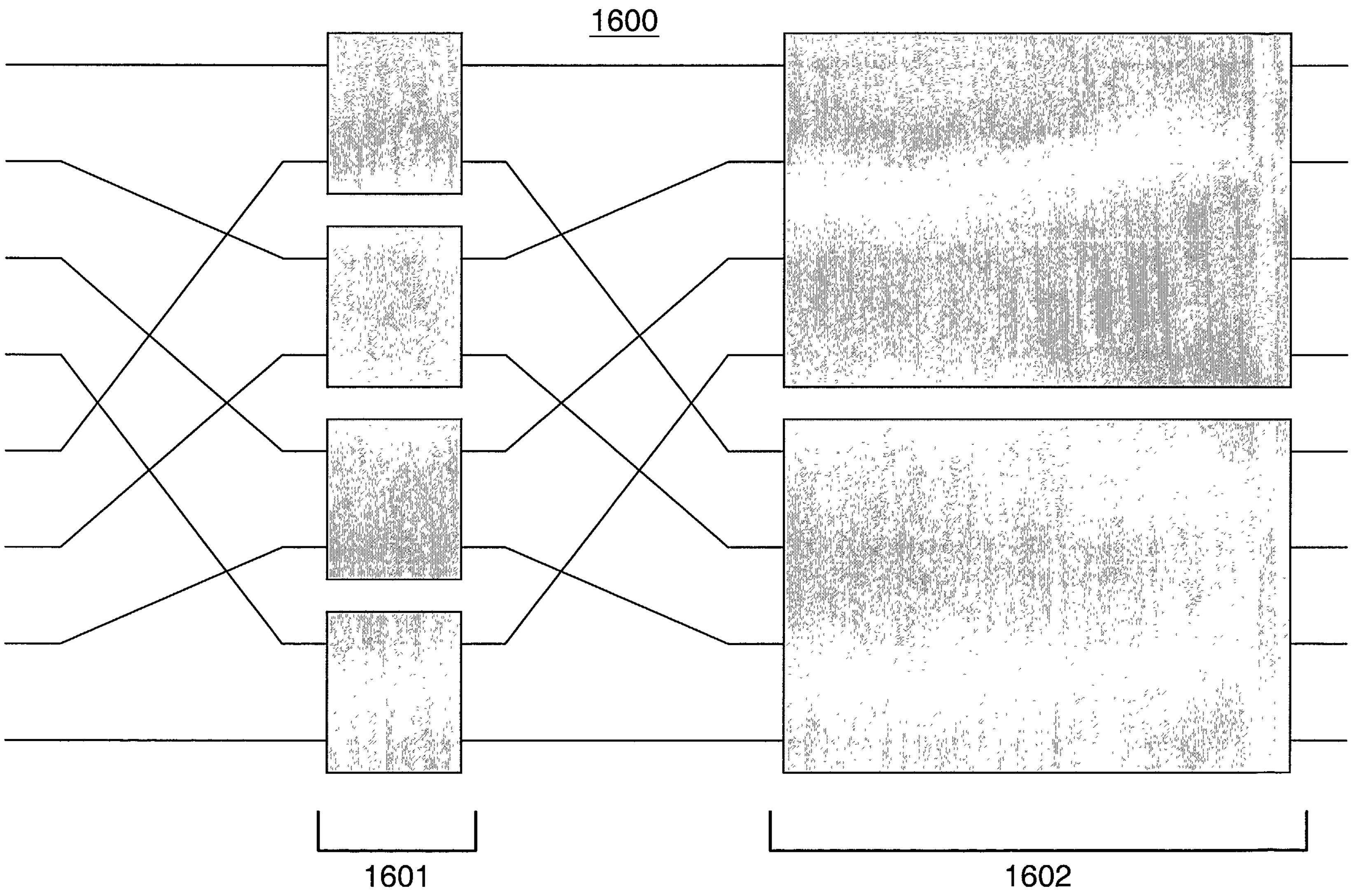


FIG. 16

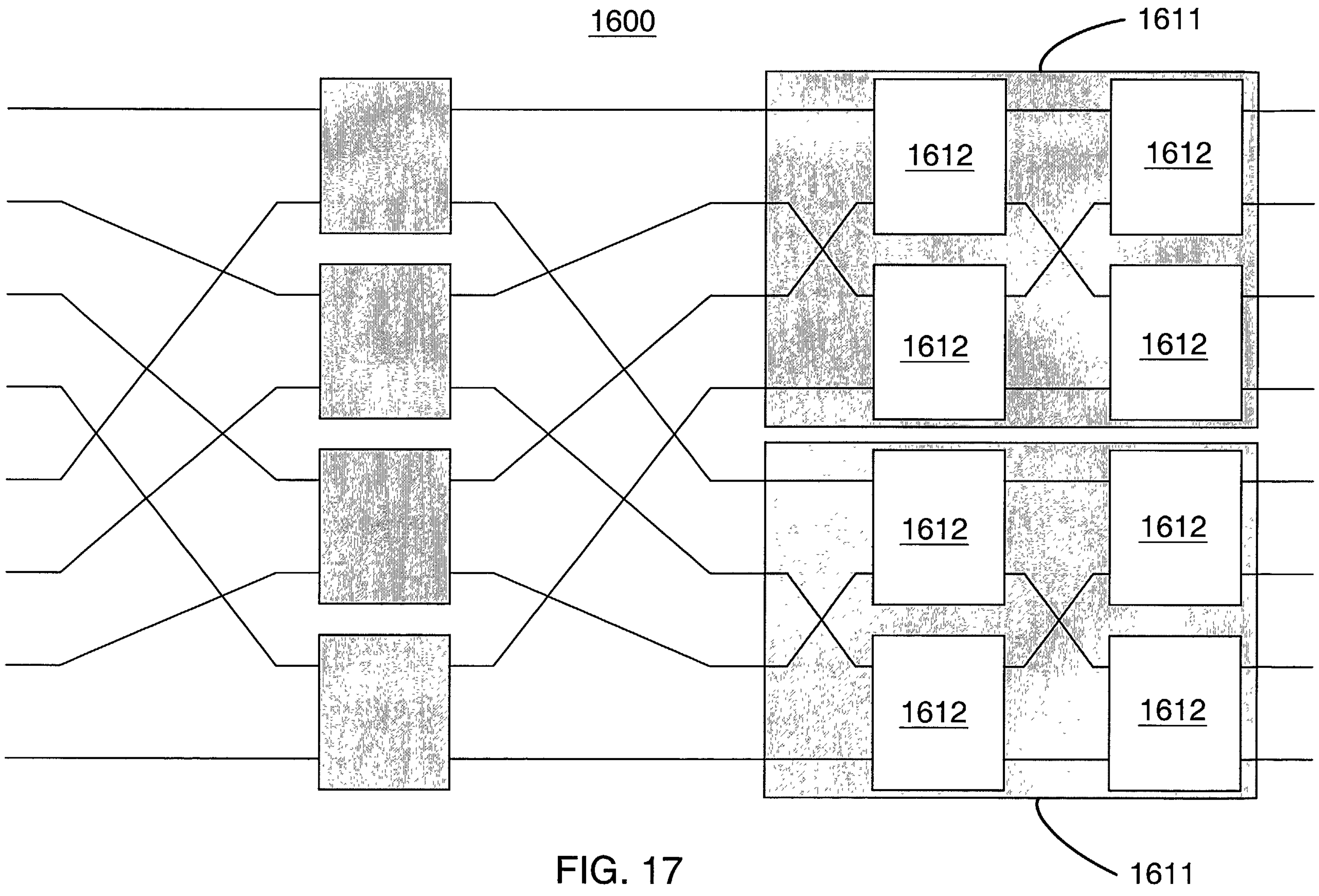


FIG. 17

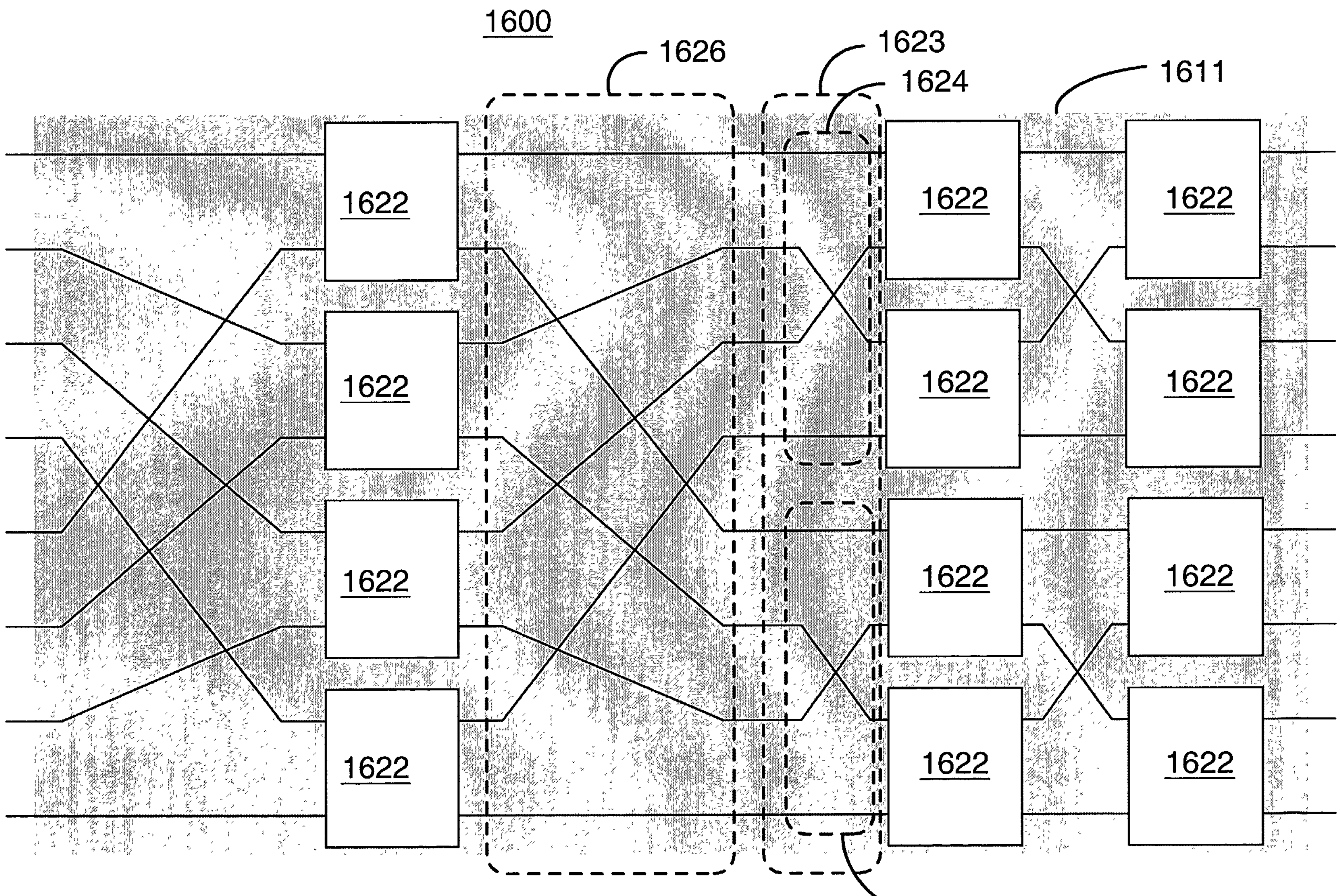

1600
1626
1623
1624
1611
1622
1622
1622
1622
1622
1622
1622
1622
1622
1622
1622
1622
1625

FIG. 18

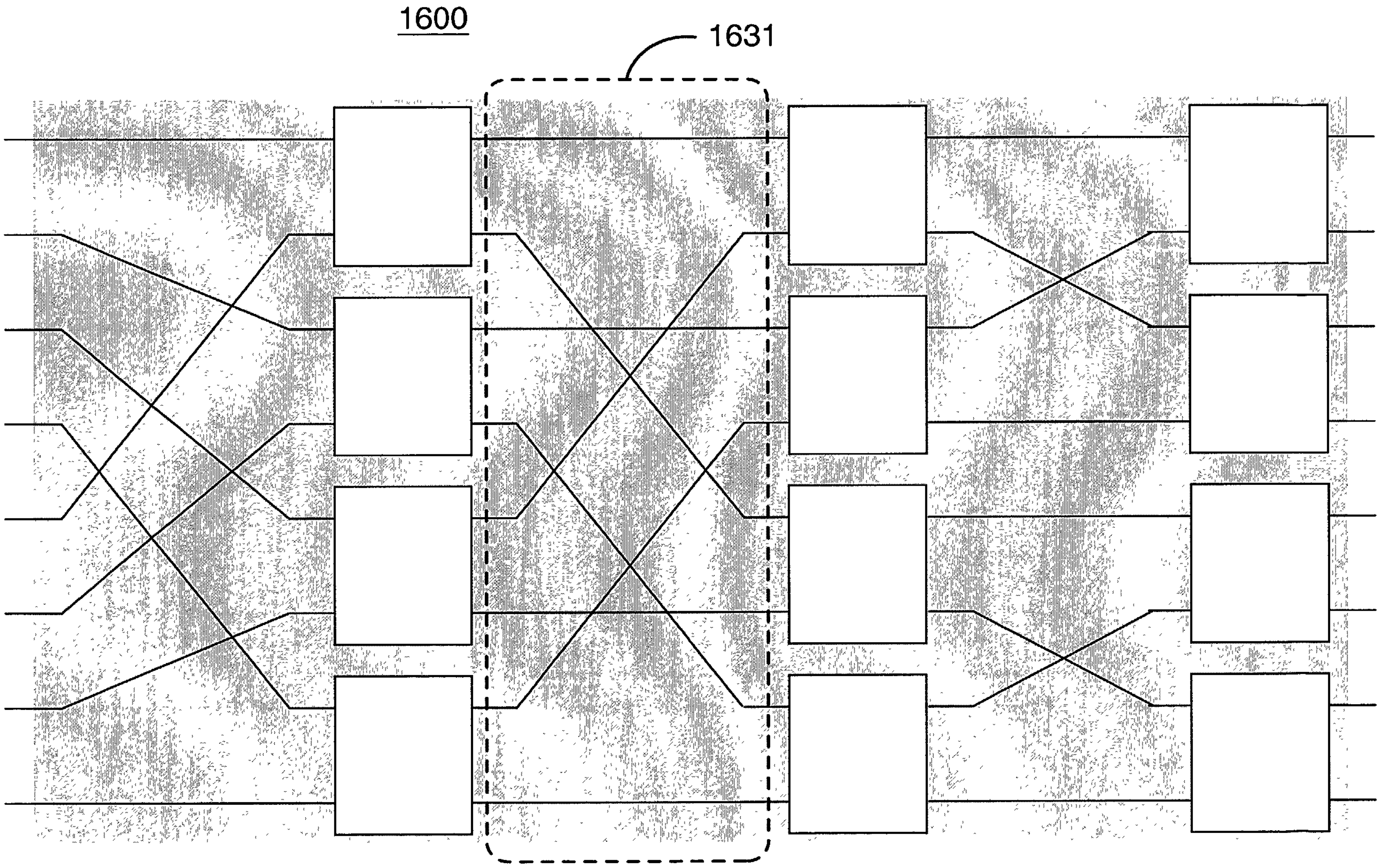


FIG. 19

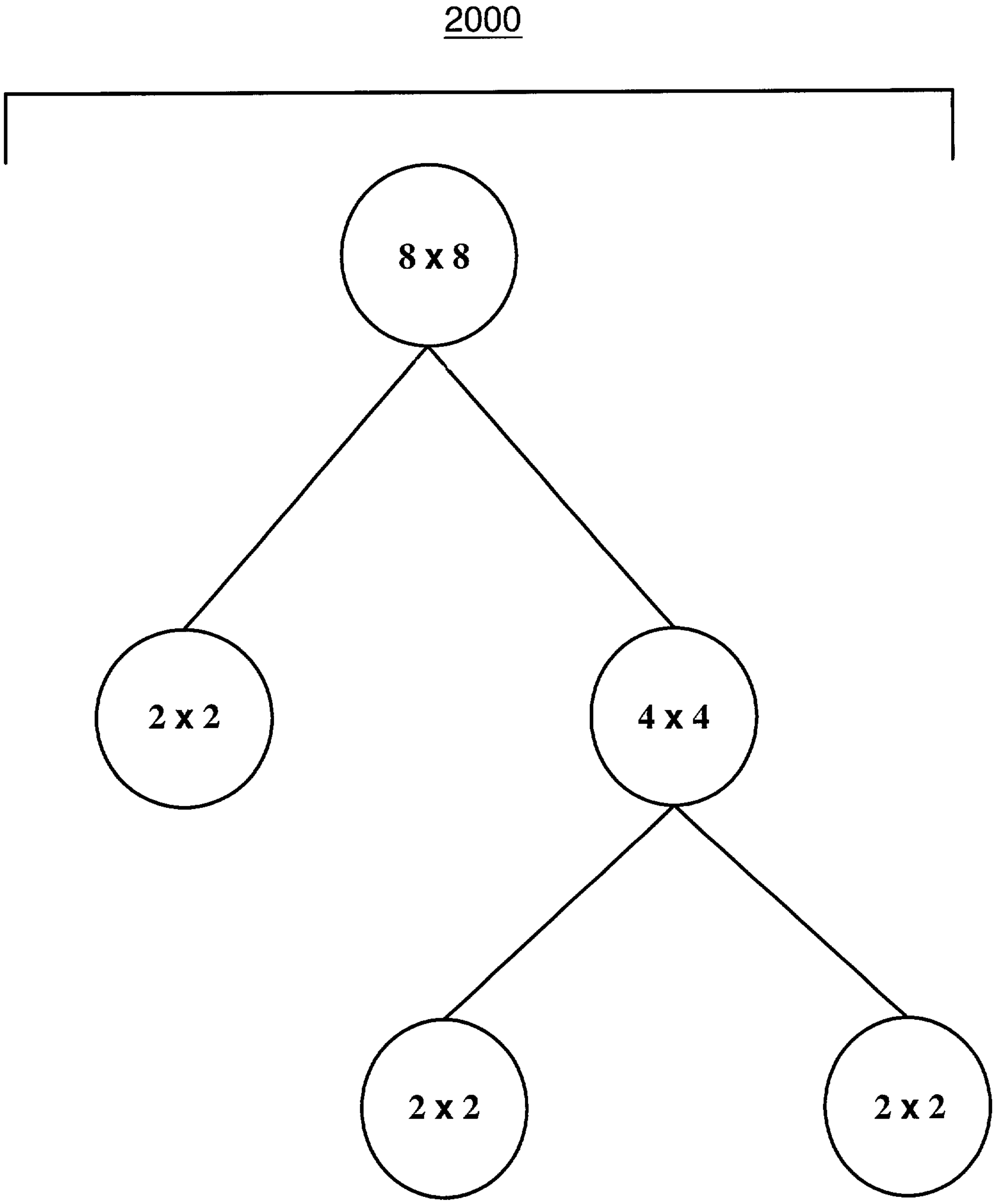


FIG. 20

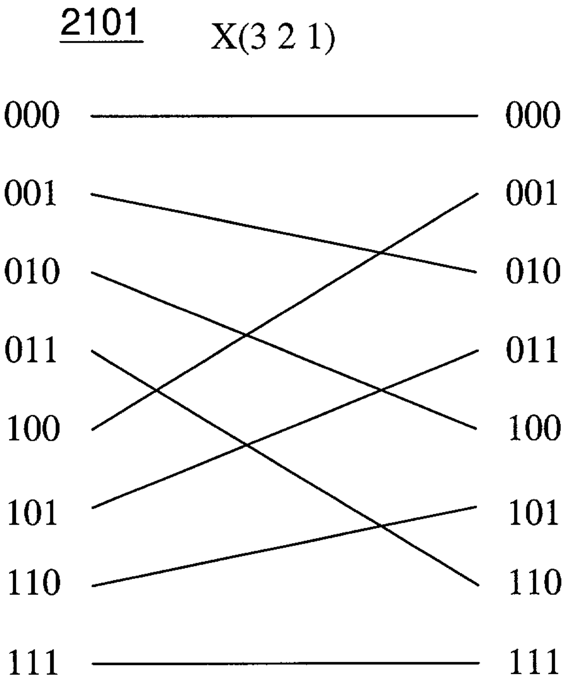


FIG. 21A

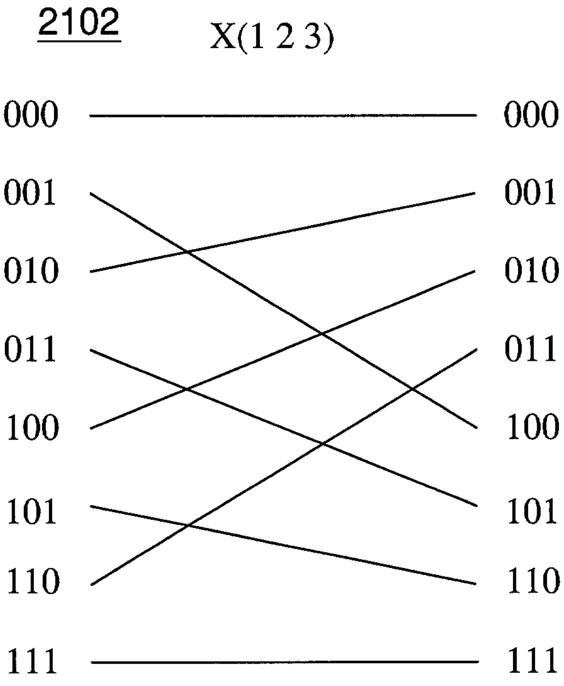


FIG. 21B

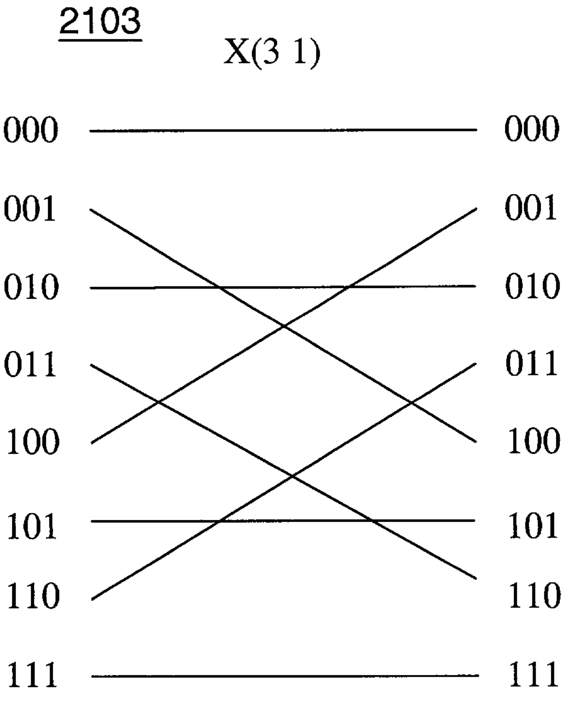


FIG. 21C

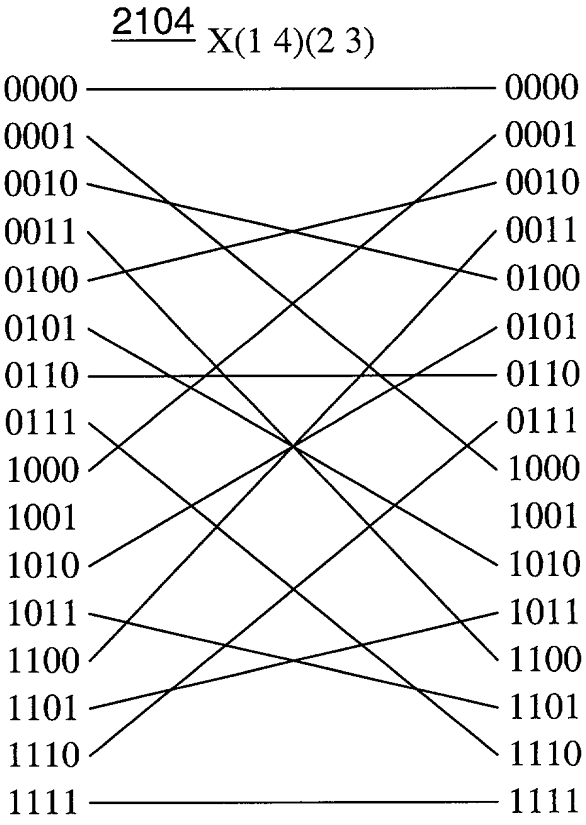
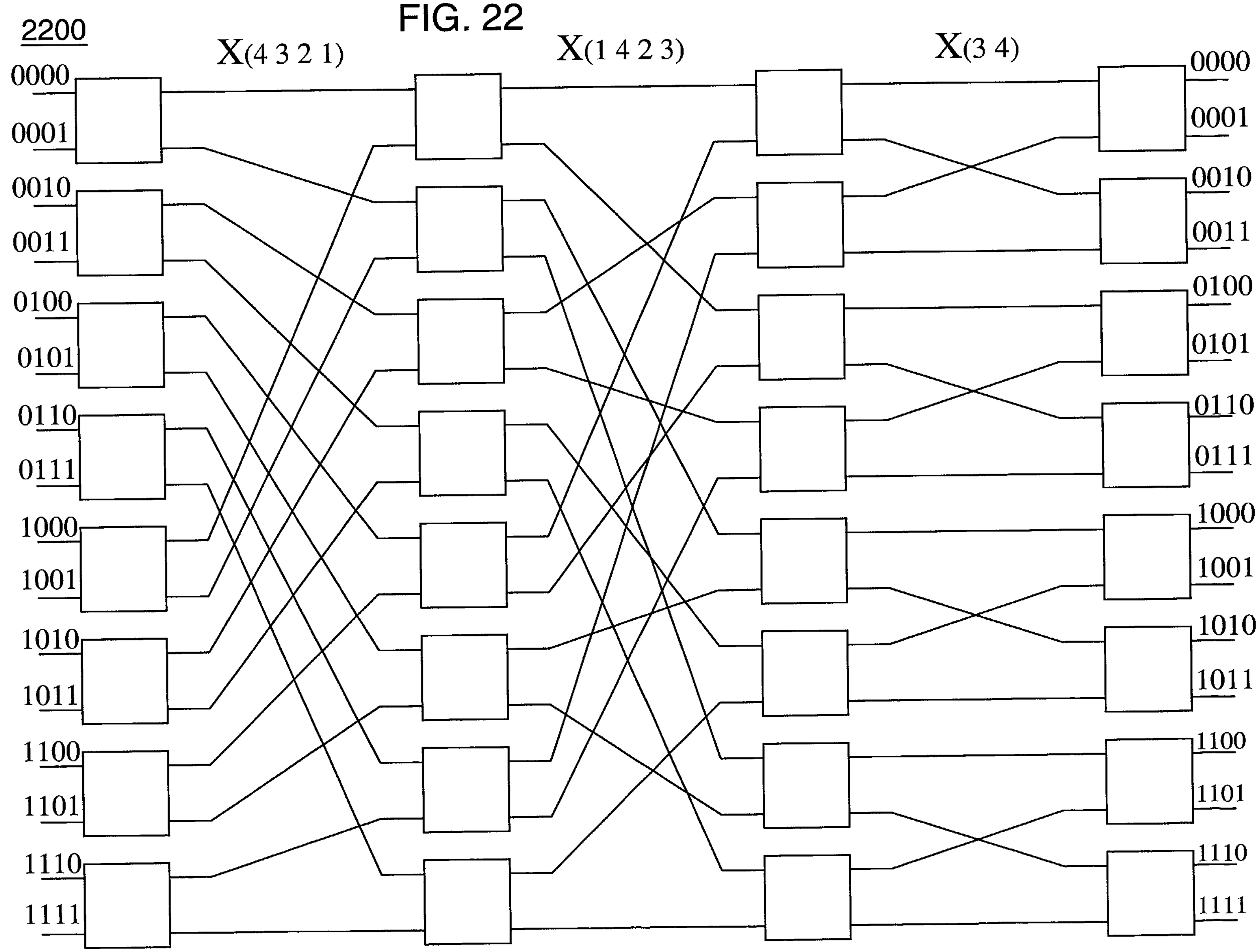


FIG. 21D

FIG. 22


2200
X(4 3 2 1)
X(1 4 2 3)
X(3 4)
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111

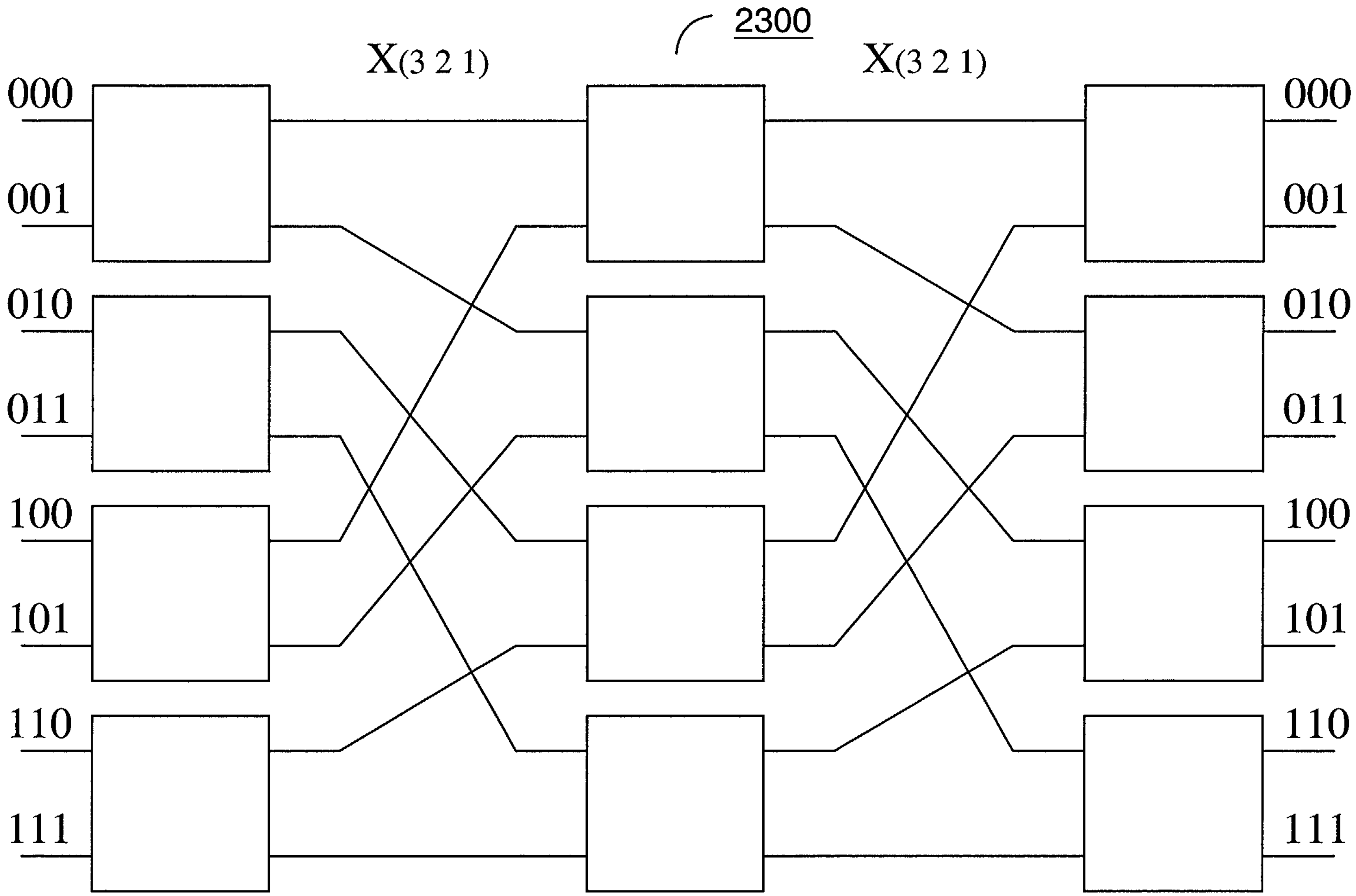

2300
X(3 2 1)
X(3 2 1)
000
001
010
011
100
101
110
111
000
001
010
011
100
101
110
111

FIG. 23

2400

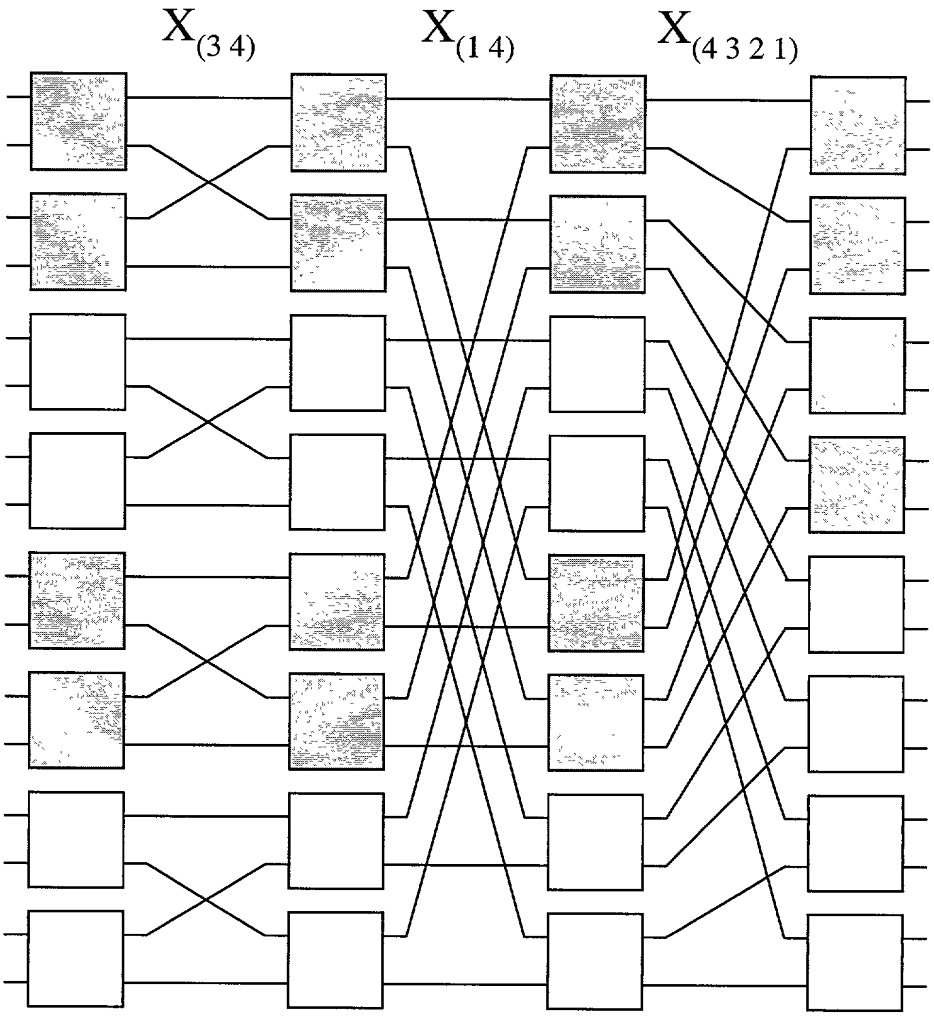


FIG. 24

FIG. 25

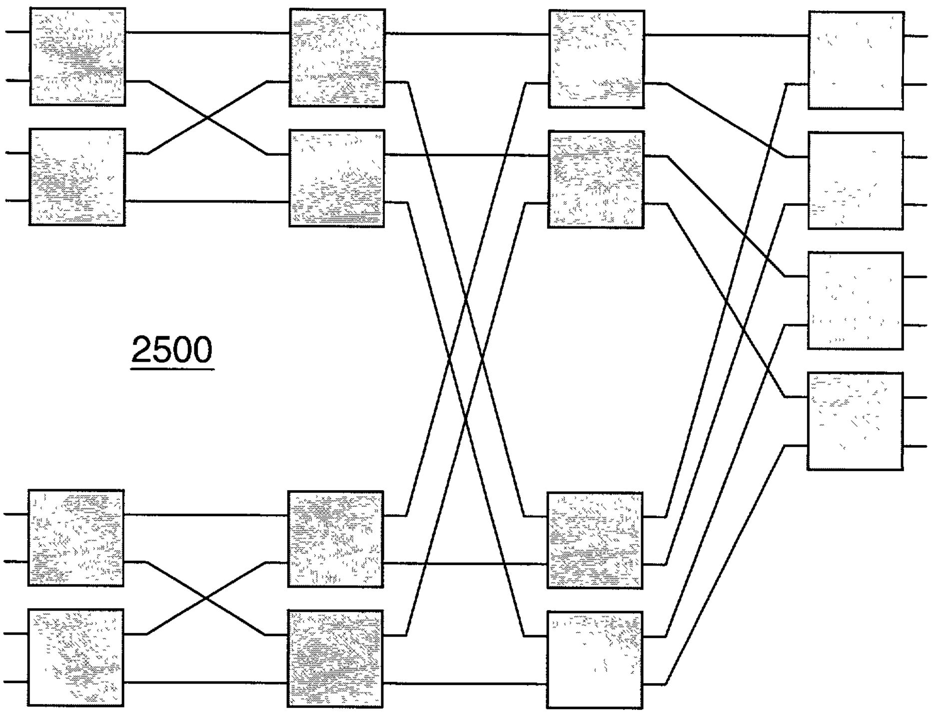
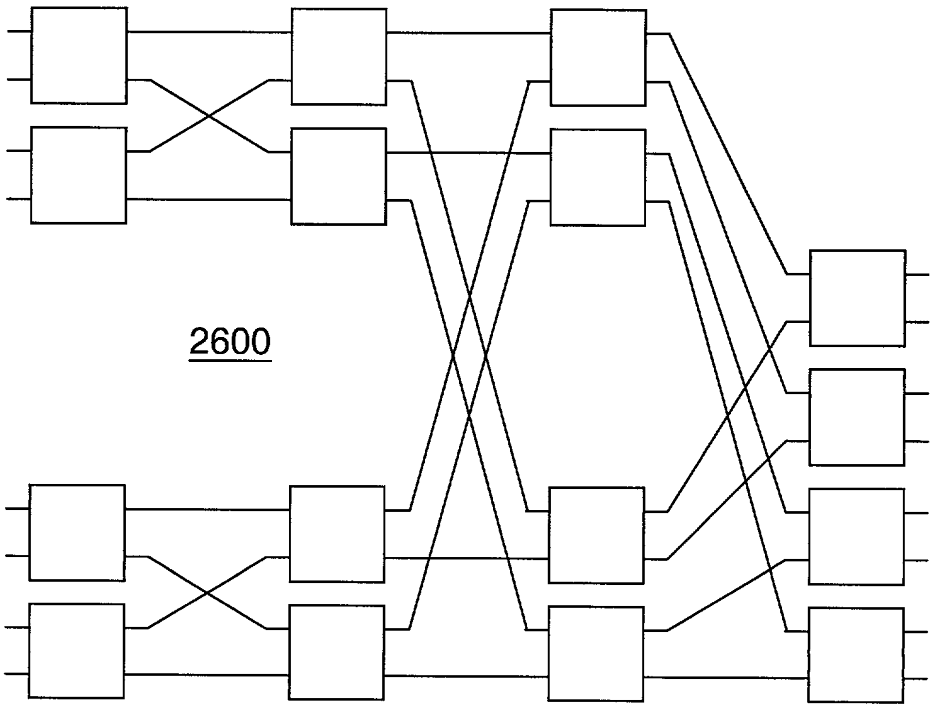


FIG. 26



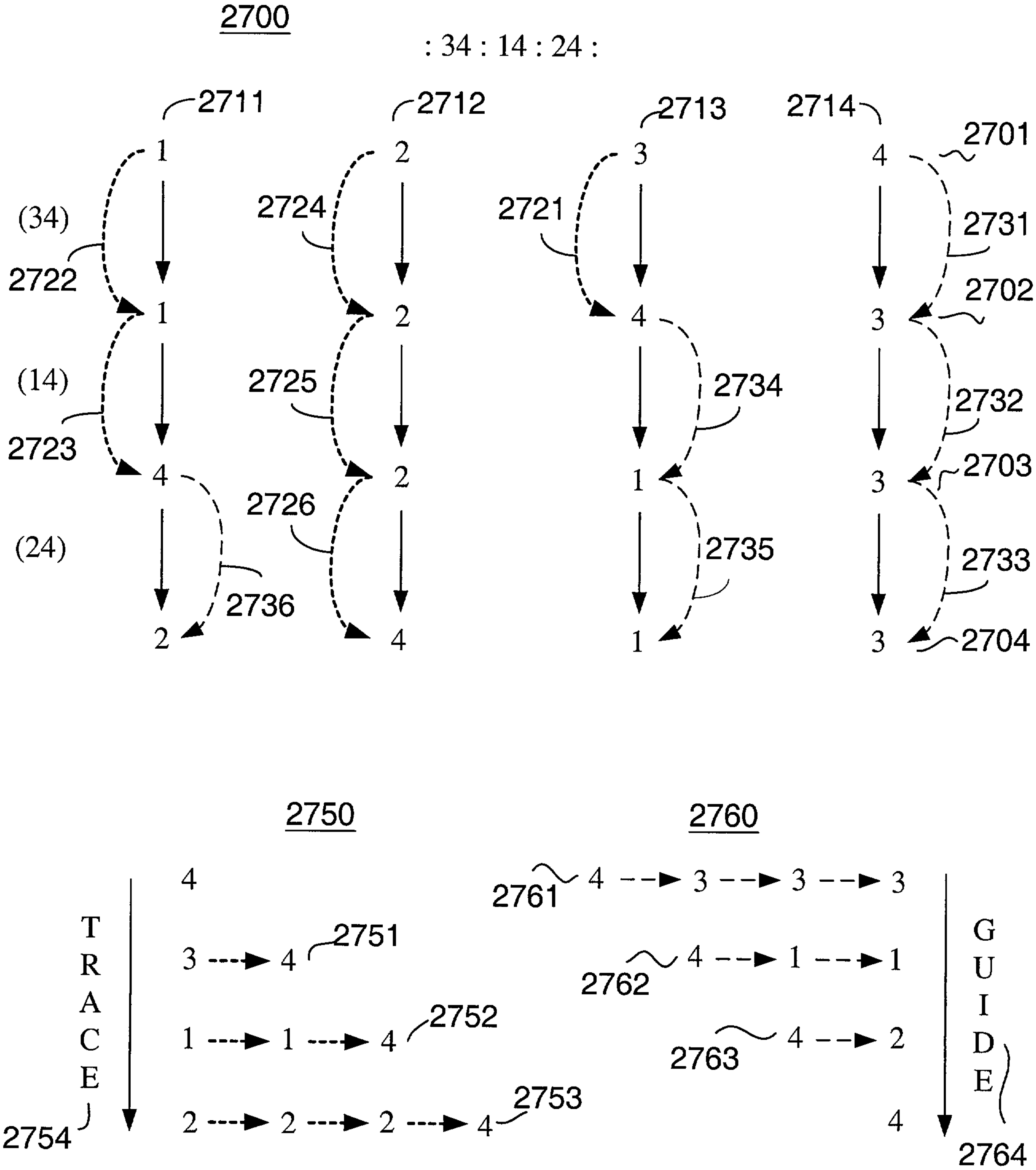

2700
: 34 : 14 : 24 :
2711
2712
2713
2714
2701
1
2
3
4
(34)
2722
2724
2721
2731
1
2
4
3
2702
(14)
2723
2725
2734
2732
4
2
1
3
2703
(24)
2726
2735
2733
2736
2
4
1
3
2704
2750
2760
T R A C E
2754
4
3 → 4
2751
1 → 1 → 4
2752
2 → 2 → 2 → 4
2753
2761
4 → 3 → 3 → 3
2762
4 → 1 → 1
2763
4 → 2
4
G U I D E
2764

FIG. 27

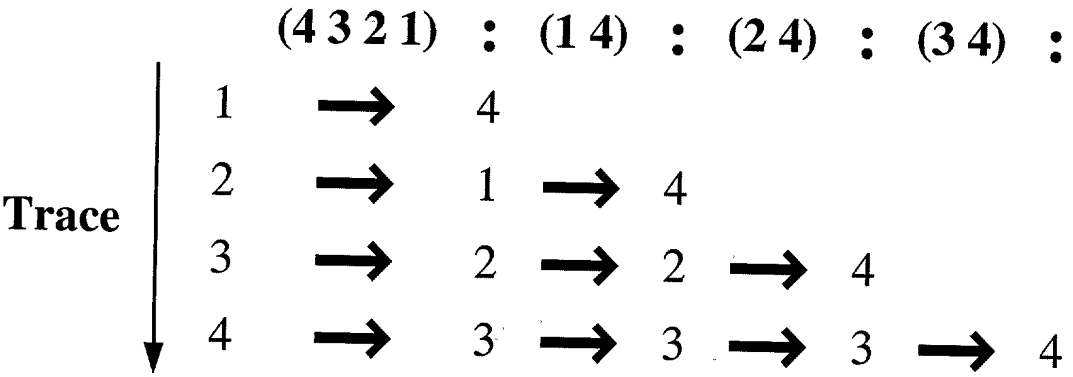


FIG. 28A

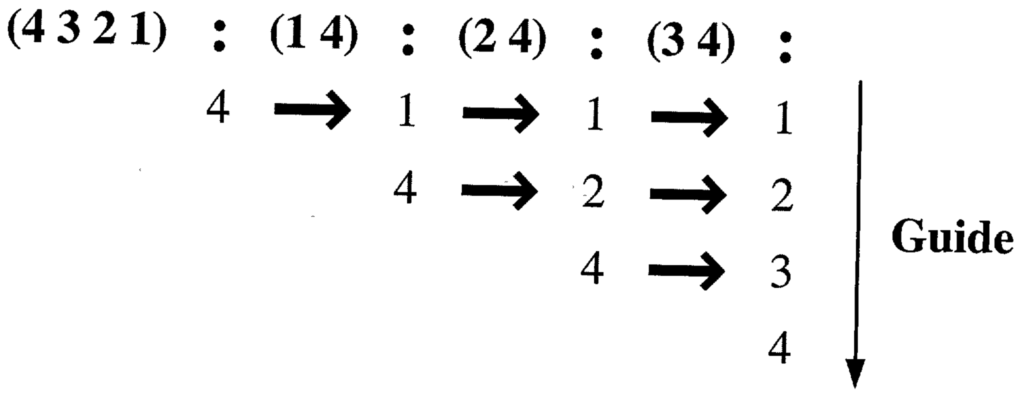


FIG. 28B

FIG. 29

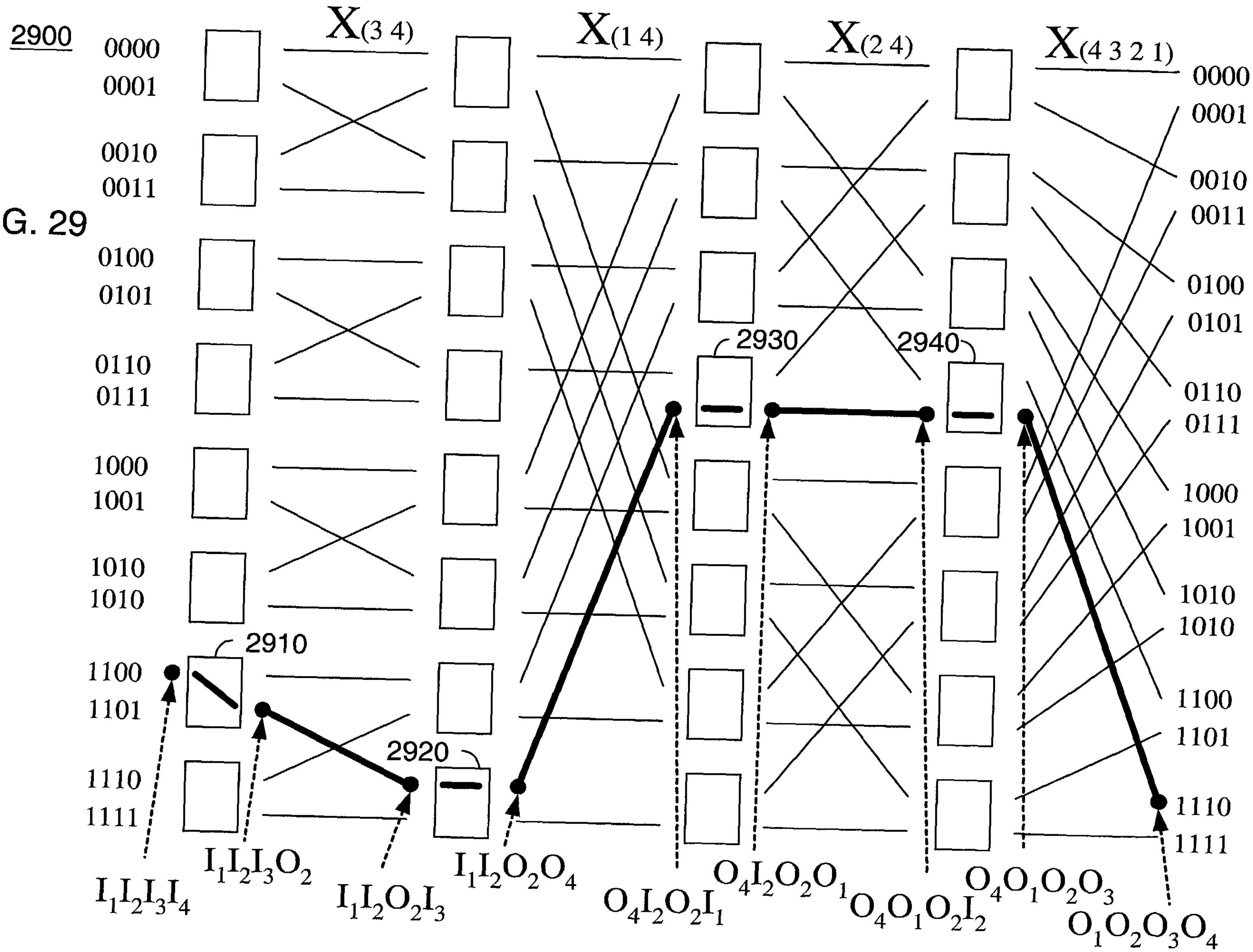

2900
X(3 4)
X(1 4)
X(2 4)
X(4 3 2 1)
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1010
1100
1101
1110
1111
2910
2920
2930
2940
$I_1I_2I_3I_4$
$I_1I_2I_3O_2$
$I_1I_2O_2I_3$
$I_1I_2O_2O_4$
$O_4I_2O_2I_1$
$O_4I_2O_2O_1$
$O_4O_1O_2I_2$
$O_4O_1O_2O_3$
$O_1O_2O_3O_4$

FIG. 30A

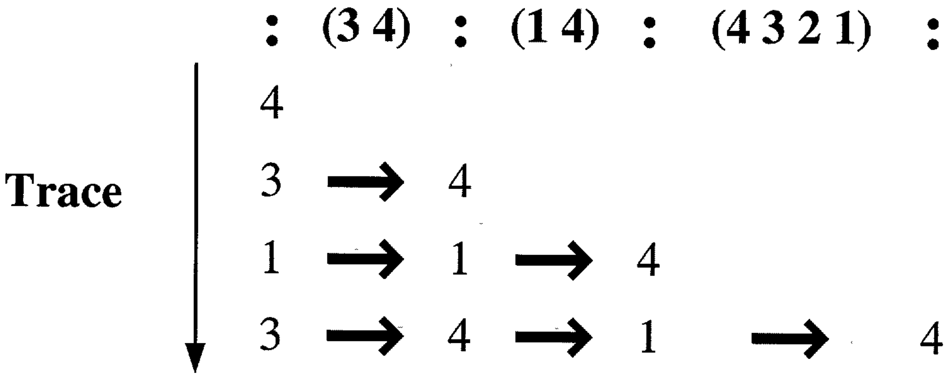
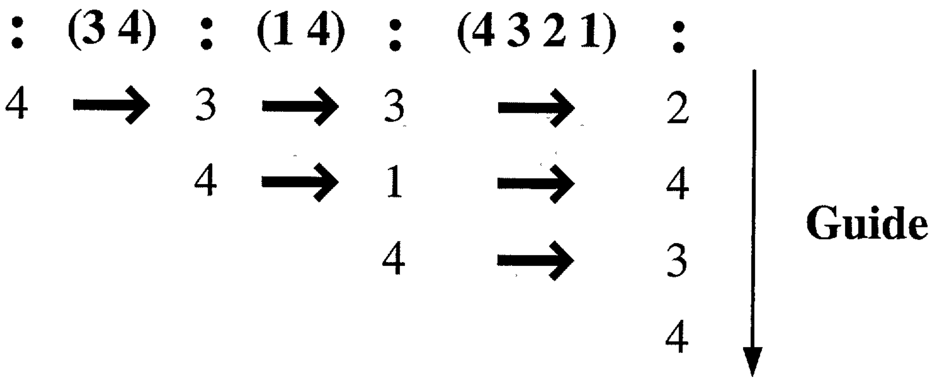
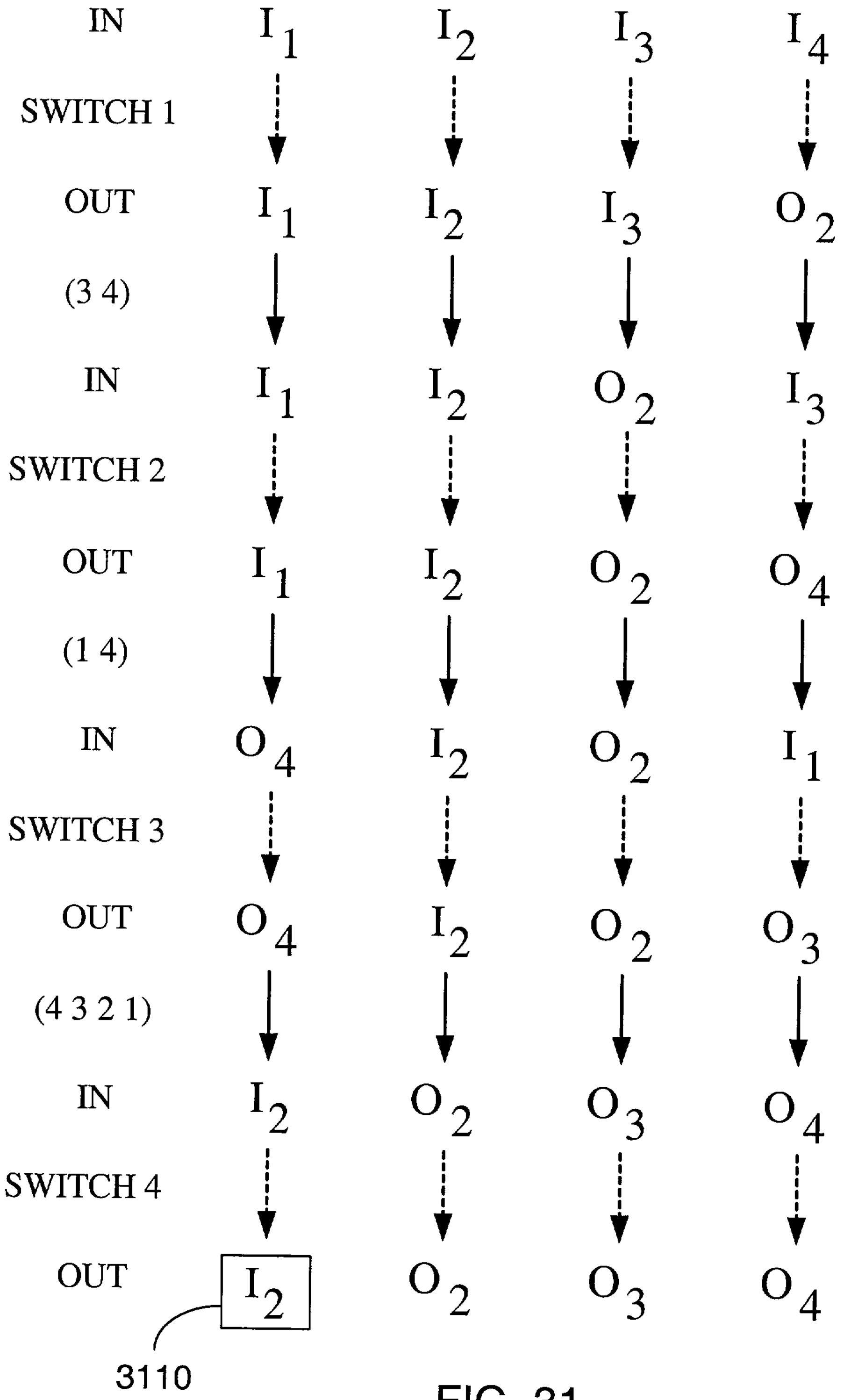


FIG. 30B



3100



IN I_1 I_2 I_3 I_4
SWITCH 1
OUT I_1 I_2 I_3 O_2
(3 4)
IN I_1 I_2 O_2 I_3
SWITCH 2
OUT I_1 I_2 O_2 O_4
(1 4)
IN O_4 I_2 O_2 I_1
SWITCH 3
OUT O_4 I_2 O_2 O_3
(4 3 2 1)
IN I_2 O_2 O_3 O_4
SWITCH 4
OUT I_2 O_2 O_3 O_4
3110

FIG. 31

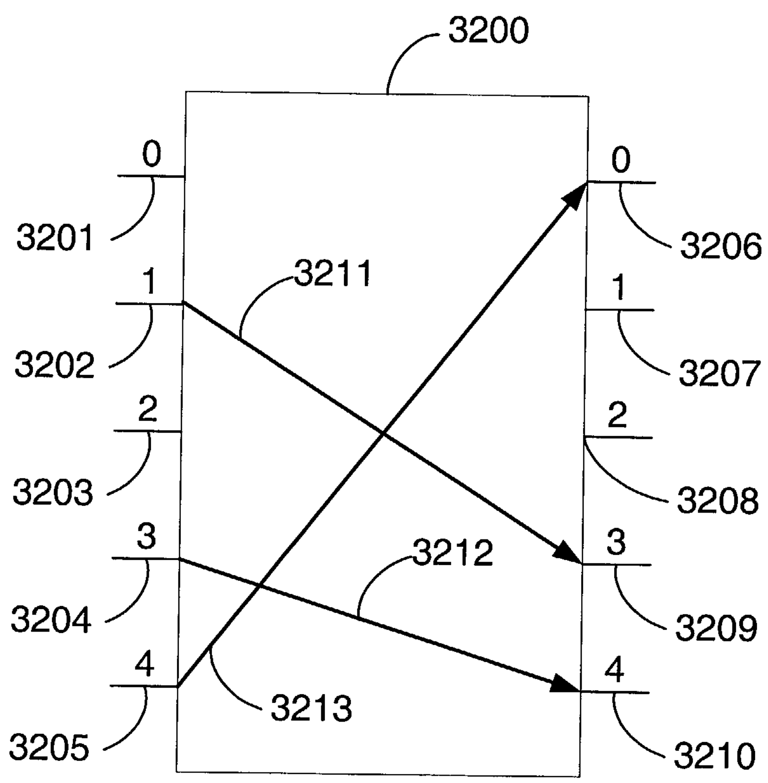


FIG. 32A

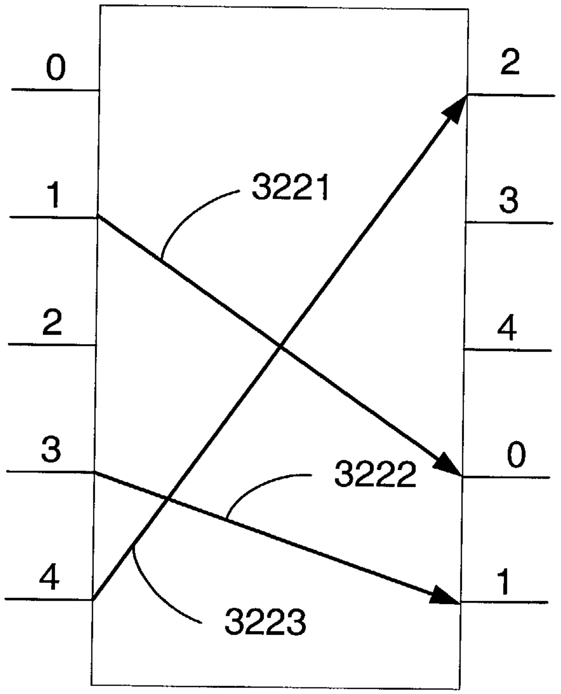


FIG. 32B

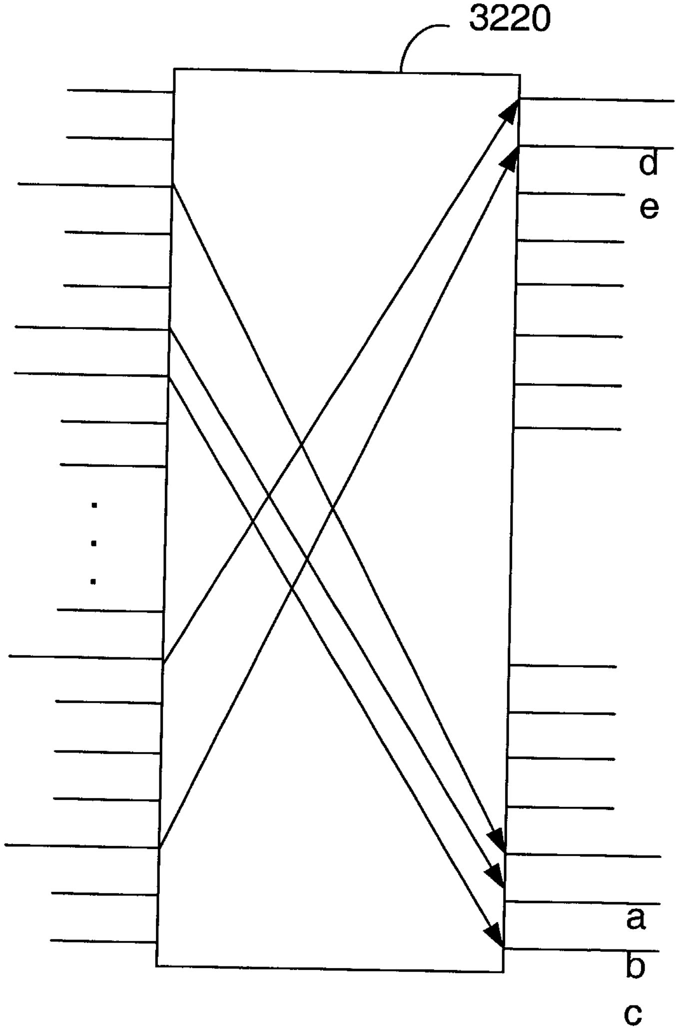


FIG. 32C

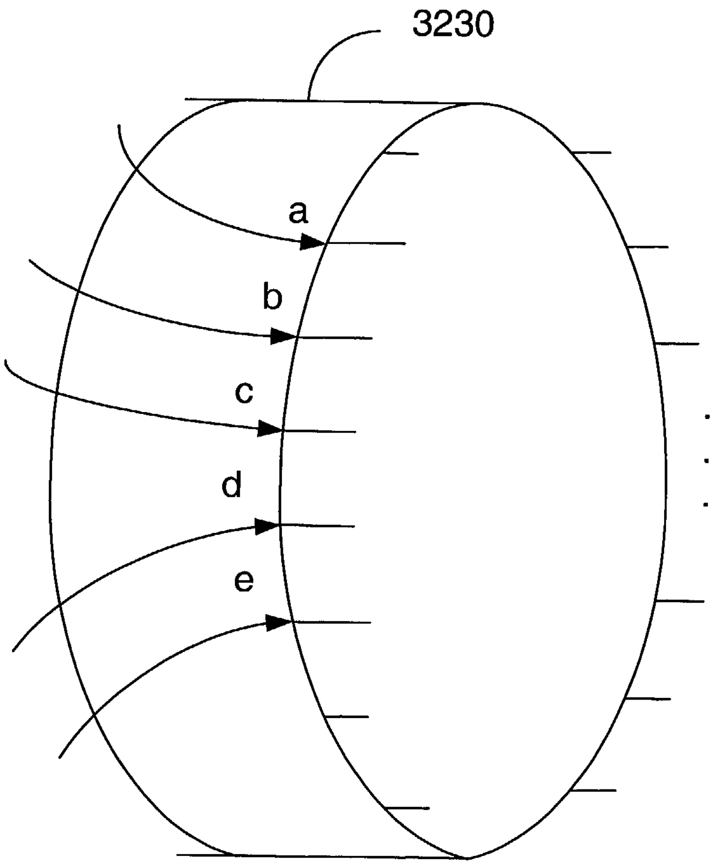


FIG. 32D

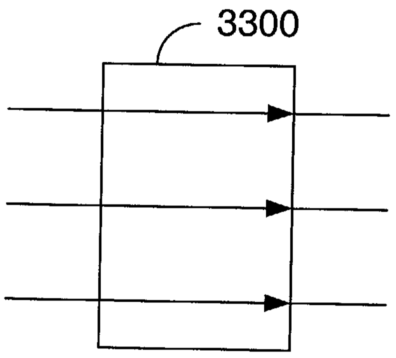


FIG. 33A

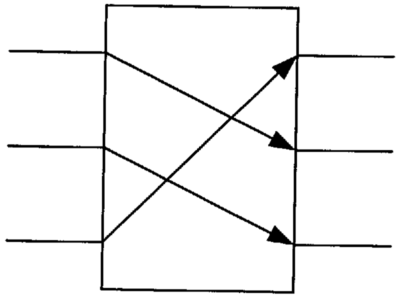


FIG. 33B

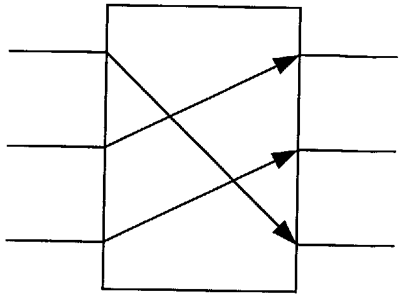


FIG. 33C

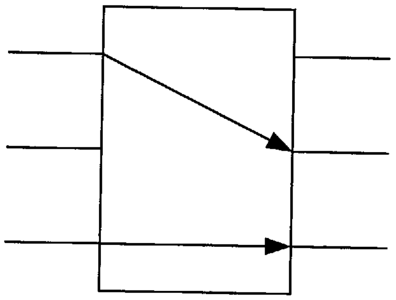


FIG. 33D

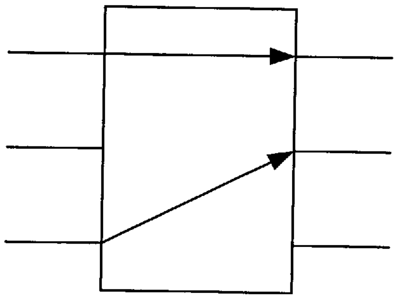


FIG. 33E

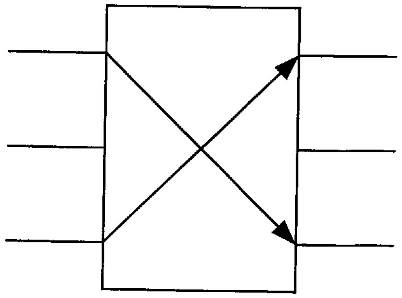


FIG.33F

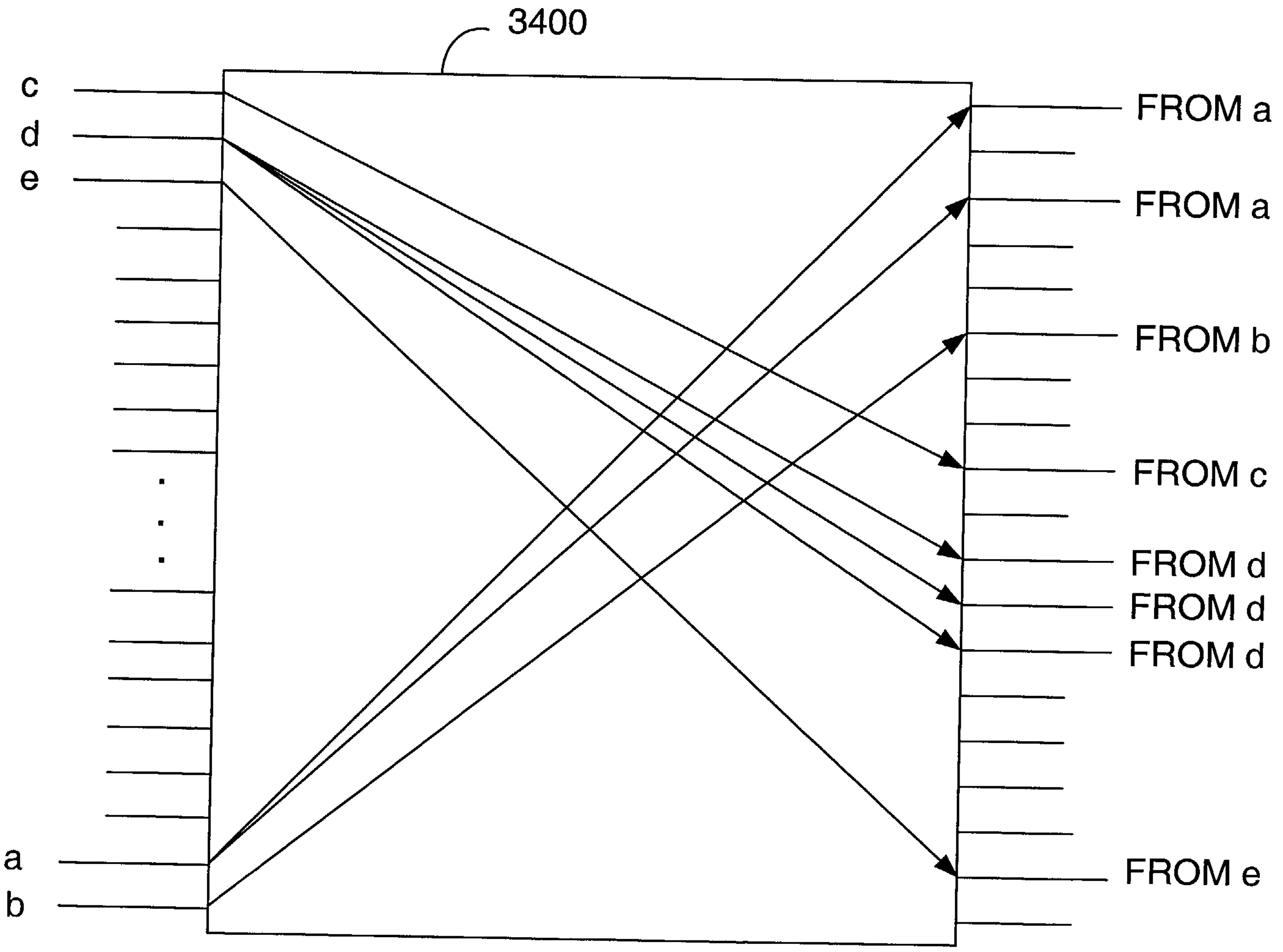


FIG. 34

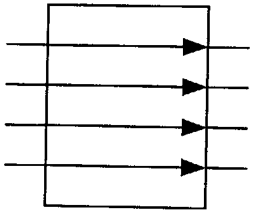


FIG. 35A

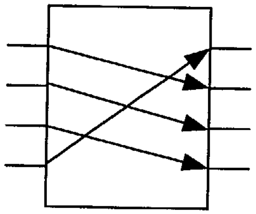


FIG. 35B

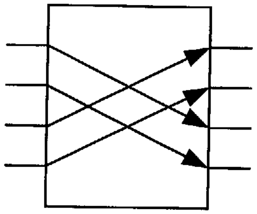


FIG. 35C

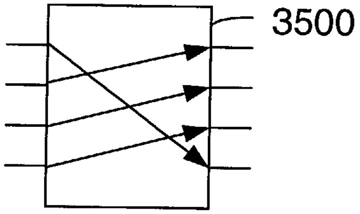


FIG. 35D

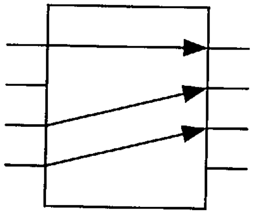


FIG. 35E

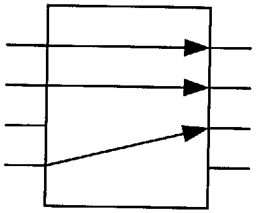


FIG. 35F

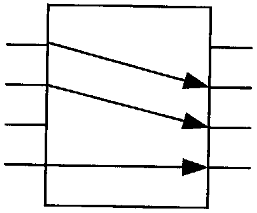


FIG. 35G

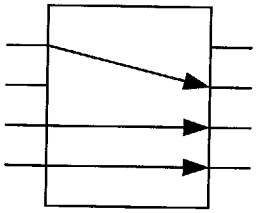


FIG. 35H

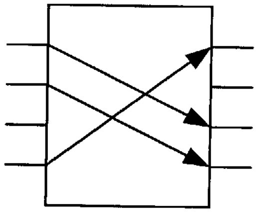


FIG. 35I

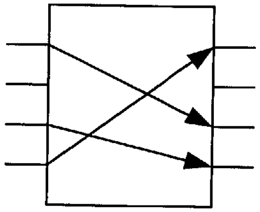


FIG. 35J

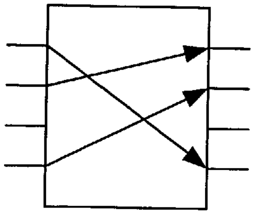


FIG. 35K

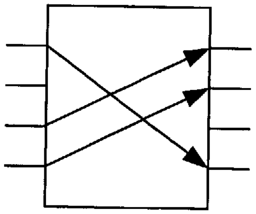


FIG. 35L

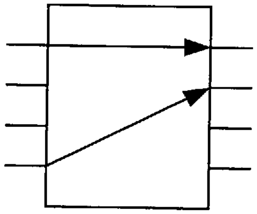


FIG. 35M

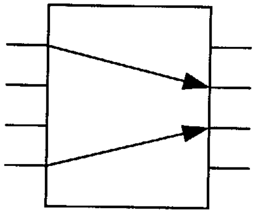


FIG. 35N

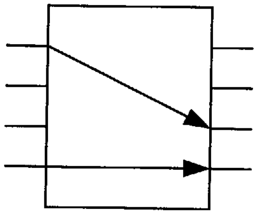


FIG. 35O

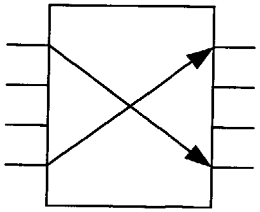


FIG. 35P

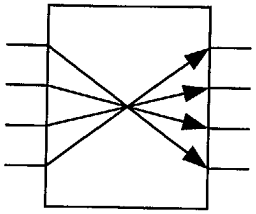


FIG. 36A

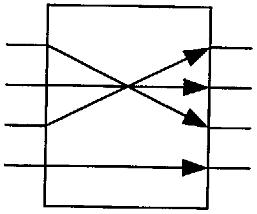


FIG. 36B

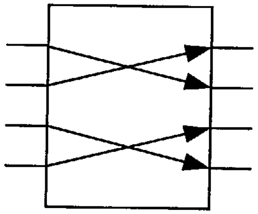


FIG. 36C

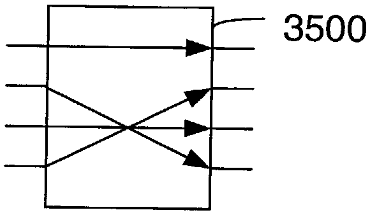


FIG. 36D

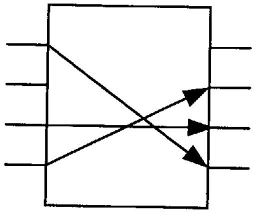


FIG. 36E

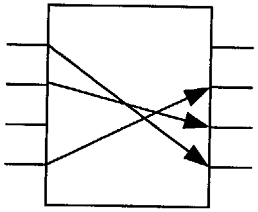


FIG. 36F

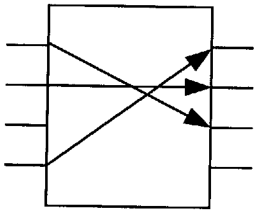


FIG. 36G

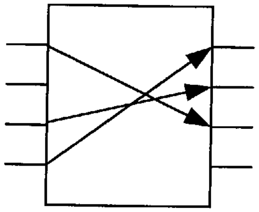


FIG. 36H

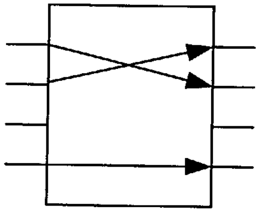


FIG. 36I

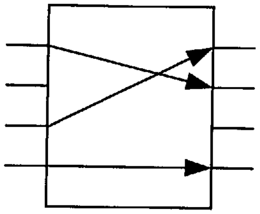


FIG. 36J

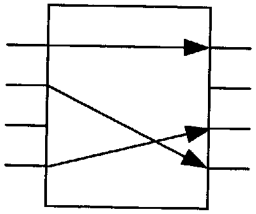


FIG. 36K

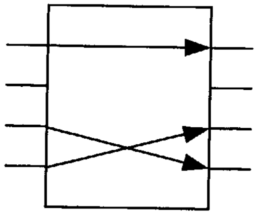


FIG. 36L

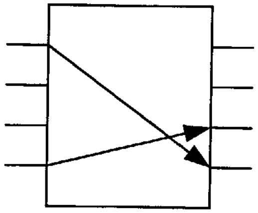


FIG. 36M

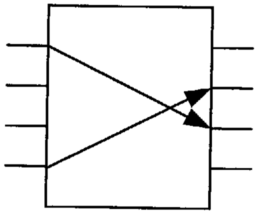


FIG. 36N

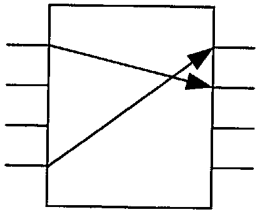


FIG. 36O

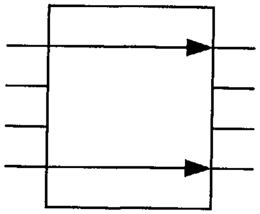


FIG. 36P

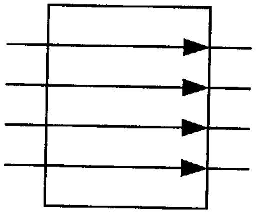


FIG. 37A

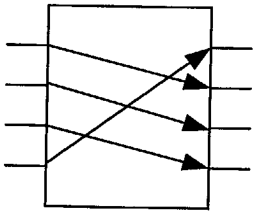


FIG. 37B

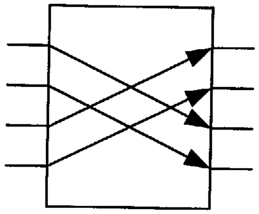


FIG. 37C

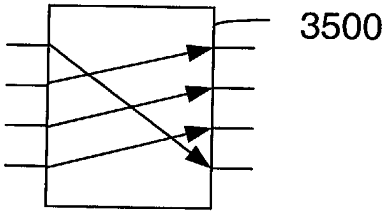


FIG. 37D

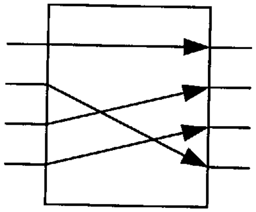


FIG. 37E

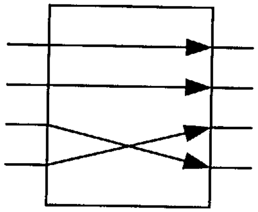


FIG. 37F

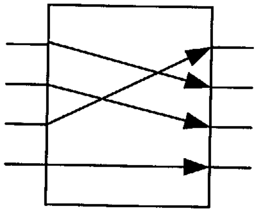


FIG. 37G

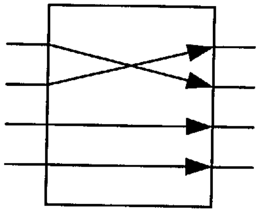


FIG. 37H

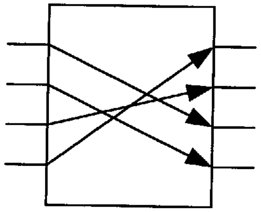


FIG. 37I

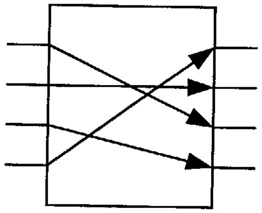


FIG. 37J

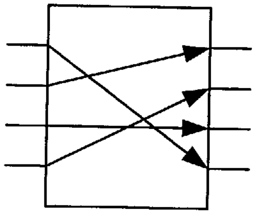


FIG. 37K

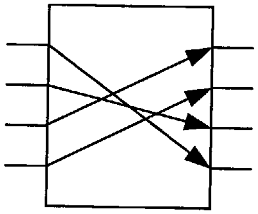


FIG. 37L

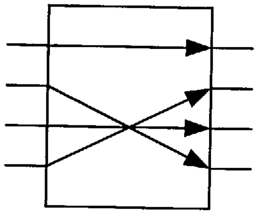


FIG. 37M

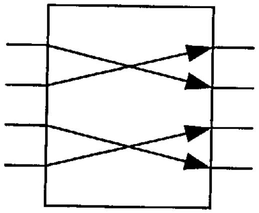


FIG. 37N

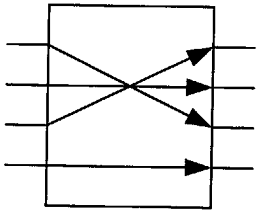


FIG. 37O

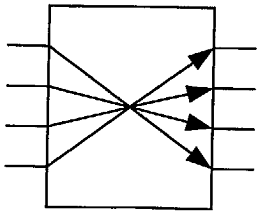


FIG. 37P

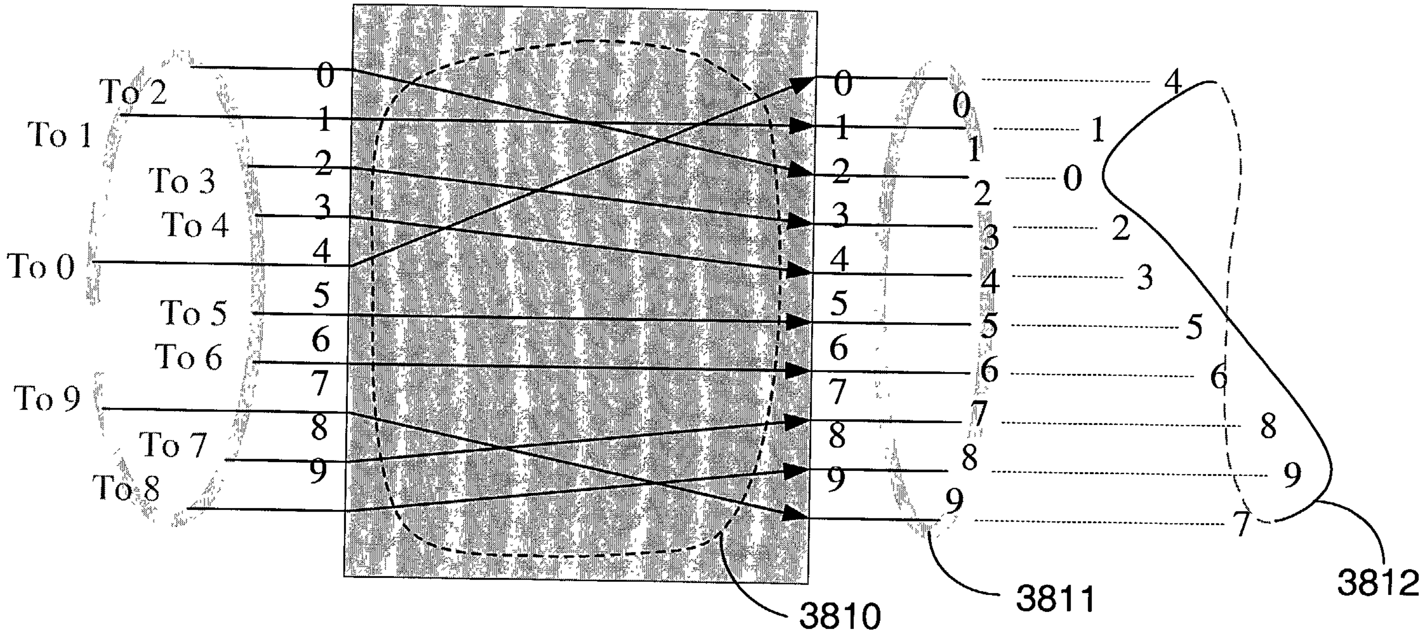

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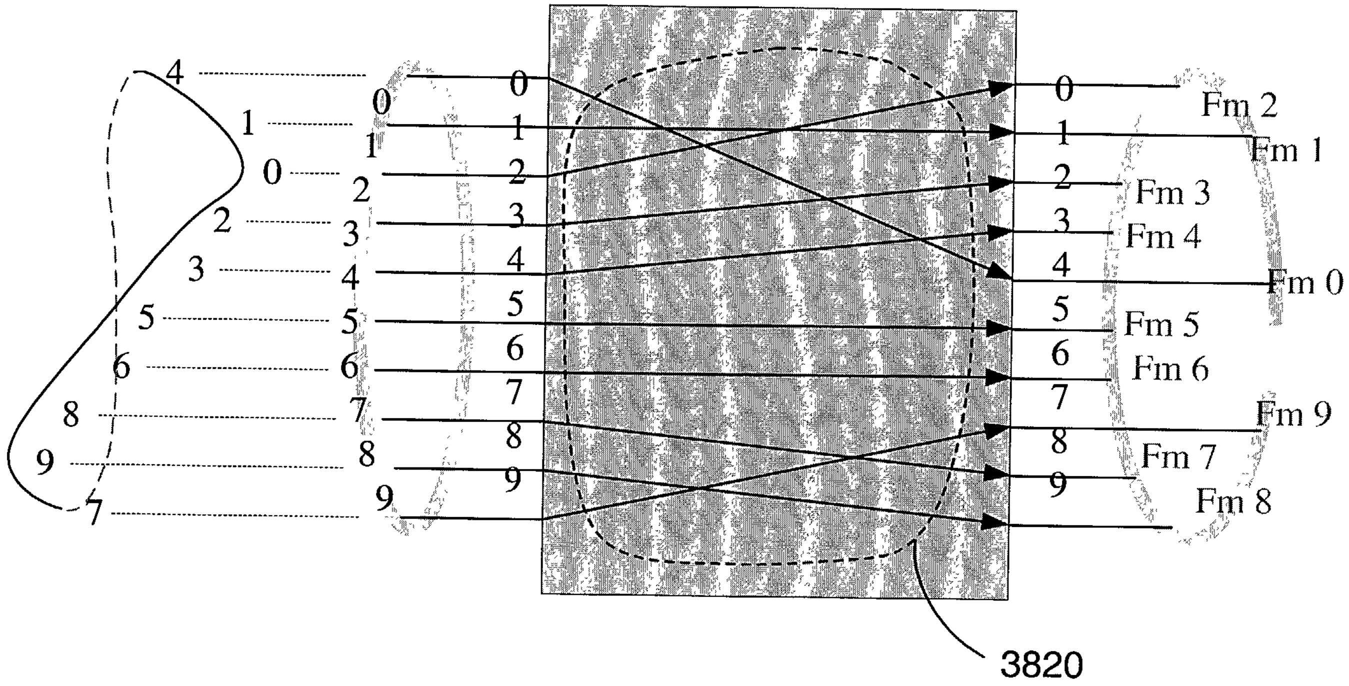
FIG. 38A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Fm 6
Fm 9
Fm 7
Fm 8
3820

FIG.38B

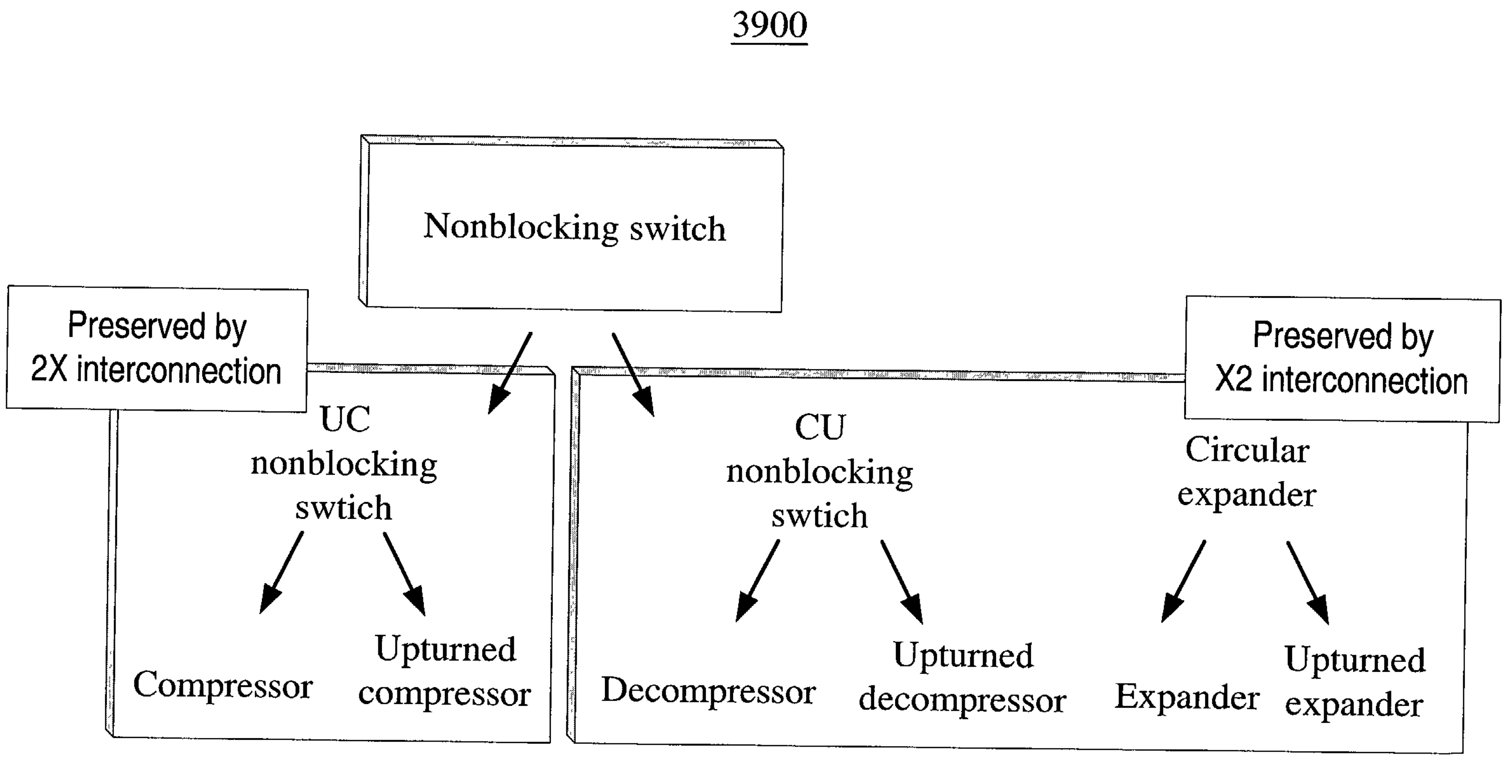
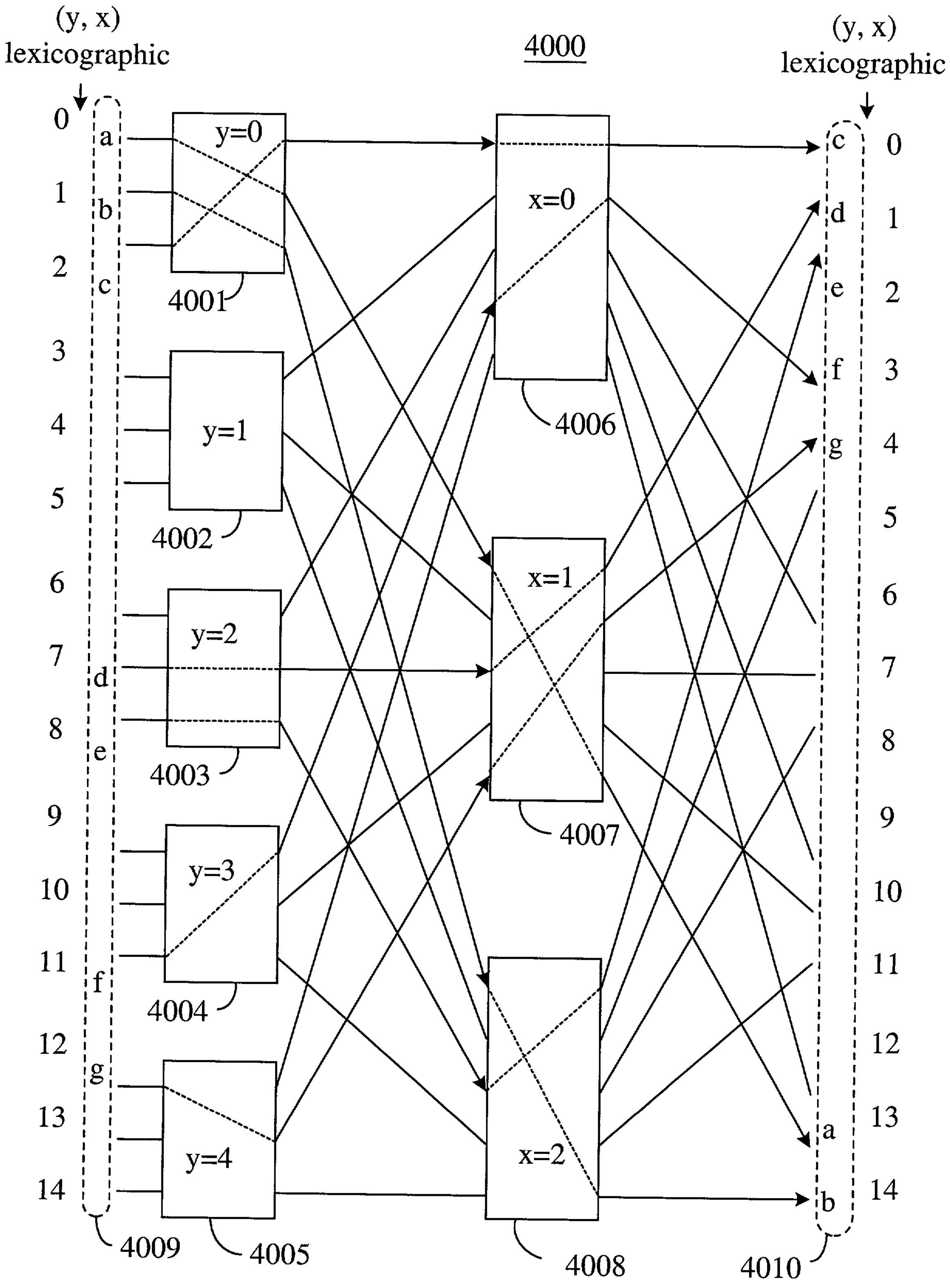

3900
Nonblocking switch
Preserved by 2X interconnection
UC nonblocking swtich
Compressor
Upturned compressor
CU nonblocking swtich
Decompressor
Upturned decompressor
Preserved by X2 interconnection
Circular expander
Expander
Upturned expander

FIG. 39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9
10
11
12
13
14
4001
4002
4003
4004
4005
4006
4007
4008
4009
4010

FIG. 40

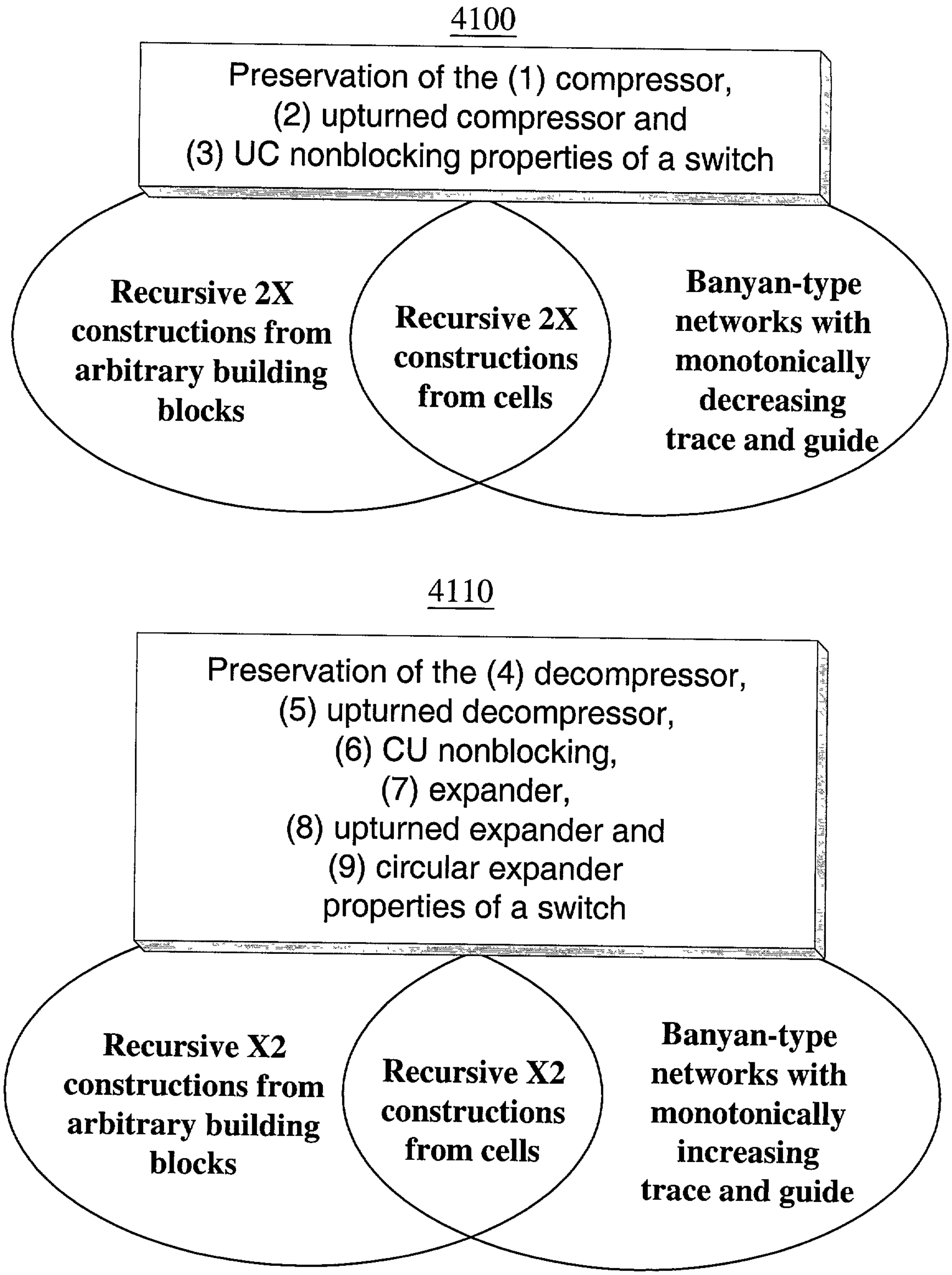

4100
Preservation of the (1) compressor, (2) upturned compressor and (3) UC nonblocking properties of a switch
Recursive 2X constructions from arbitrary building blocks
Recursive 2X constructions from cells
Banyan-type networks with monotonically decreasing trace and guide
4110
Preservation of the (4) decompressor, (5) upturned decompressor, (6) CU nonblocking, (7) expander, (8) upturned expander and (9) circular expander properties of a switch
Recursive X2 constructions from arbitrary building blocks
Recursive X2 constructions from cells
Banyan-type networks with monotonically increasing trace and guide

FIG. 41

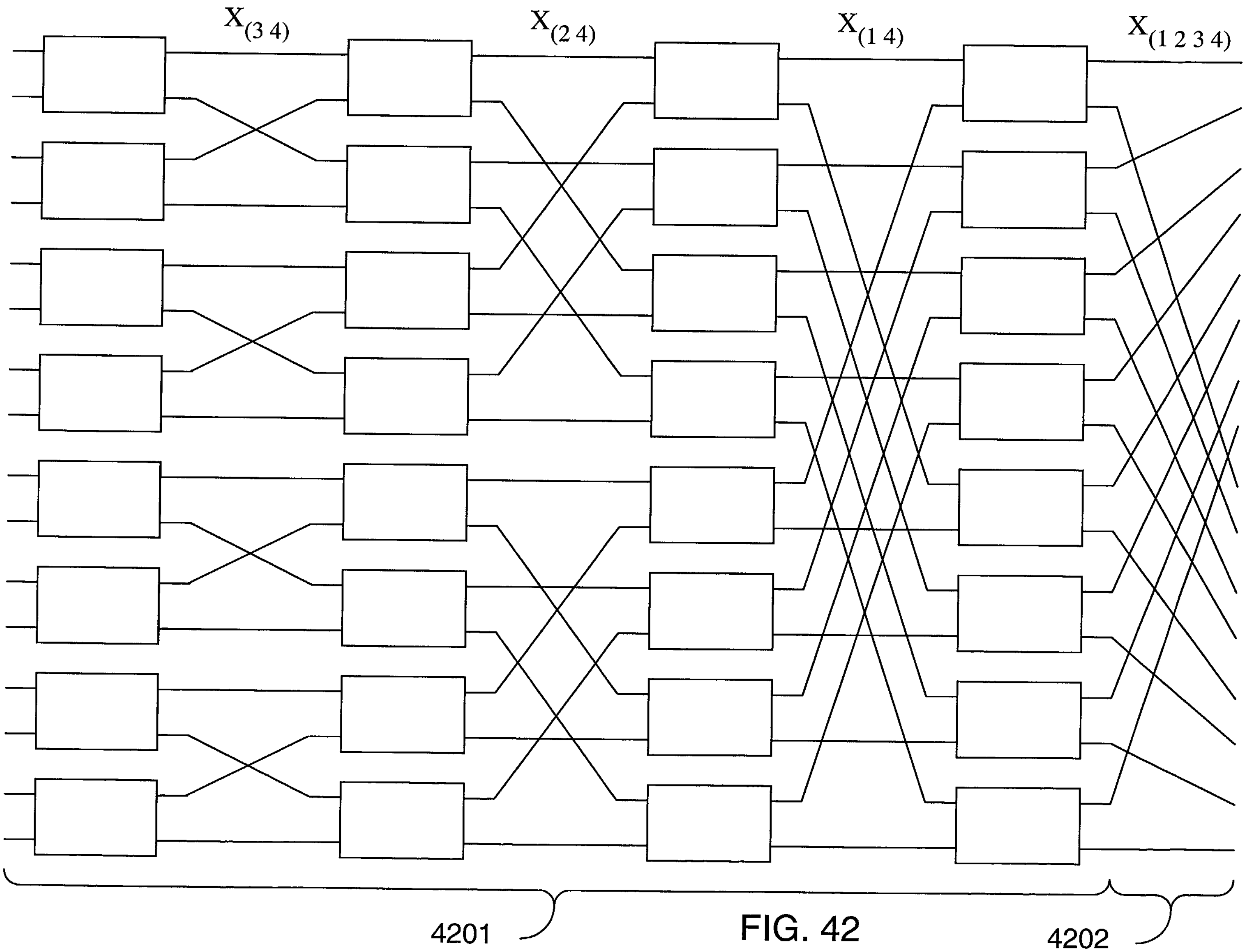


FIG. 42

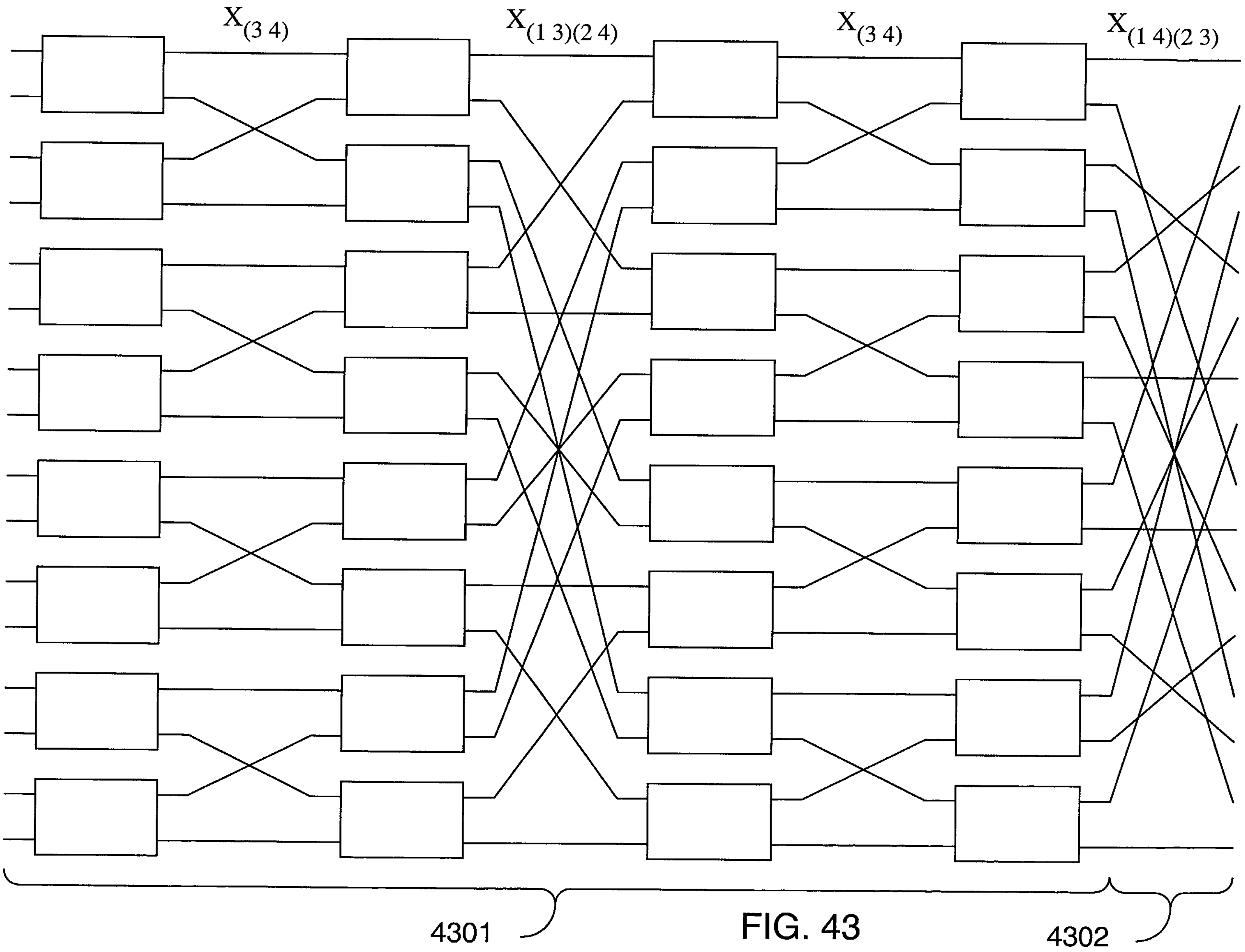


FIG. 43

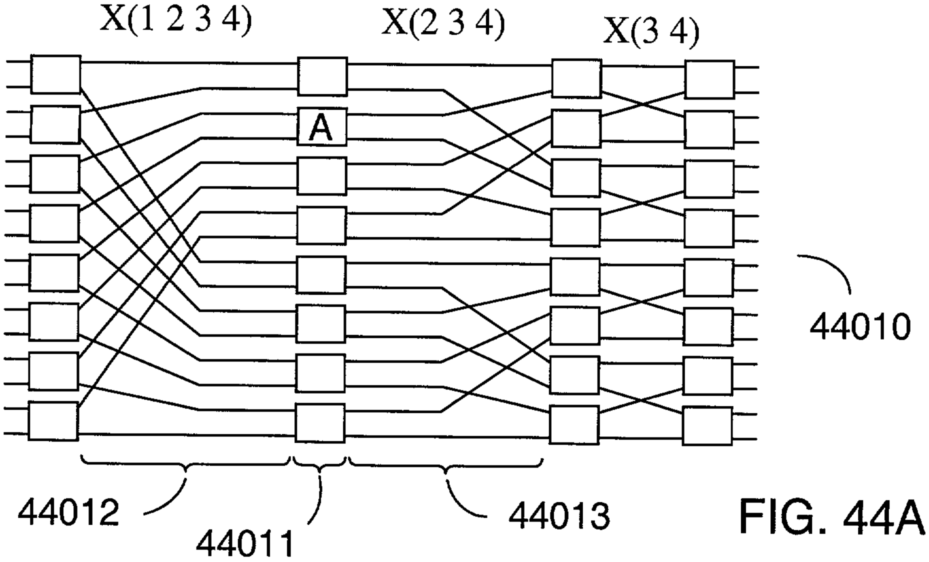


FIG. 44A

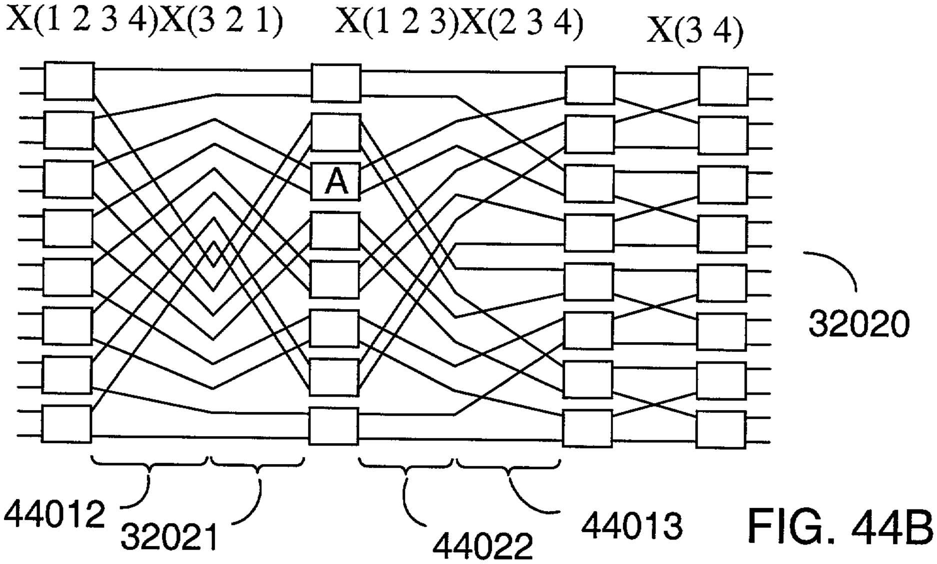


FIG. 44B

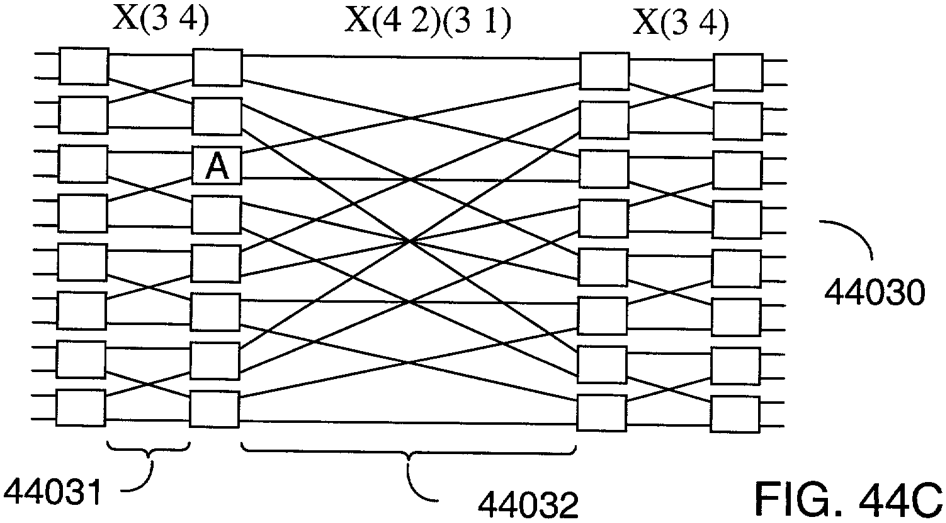


FIG. 44C

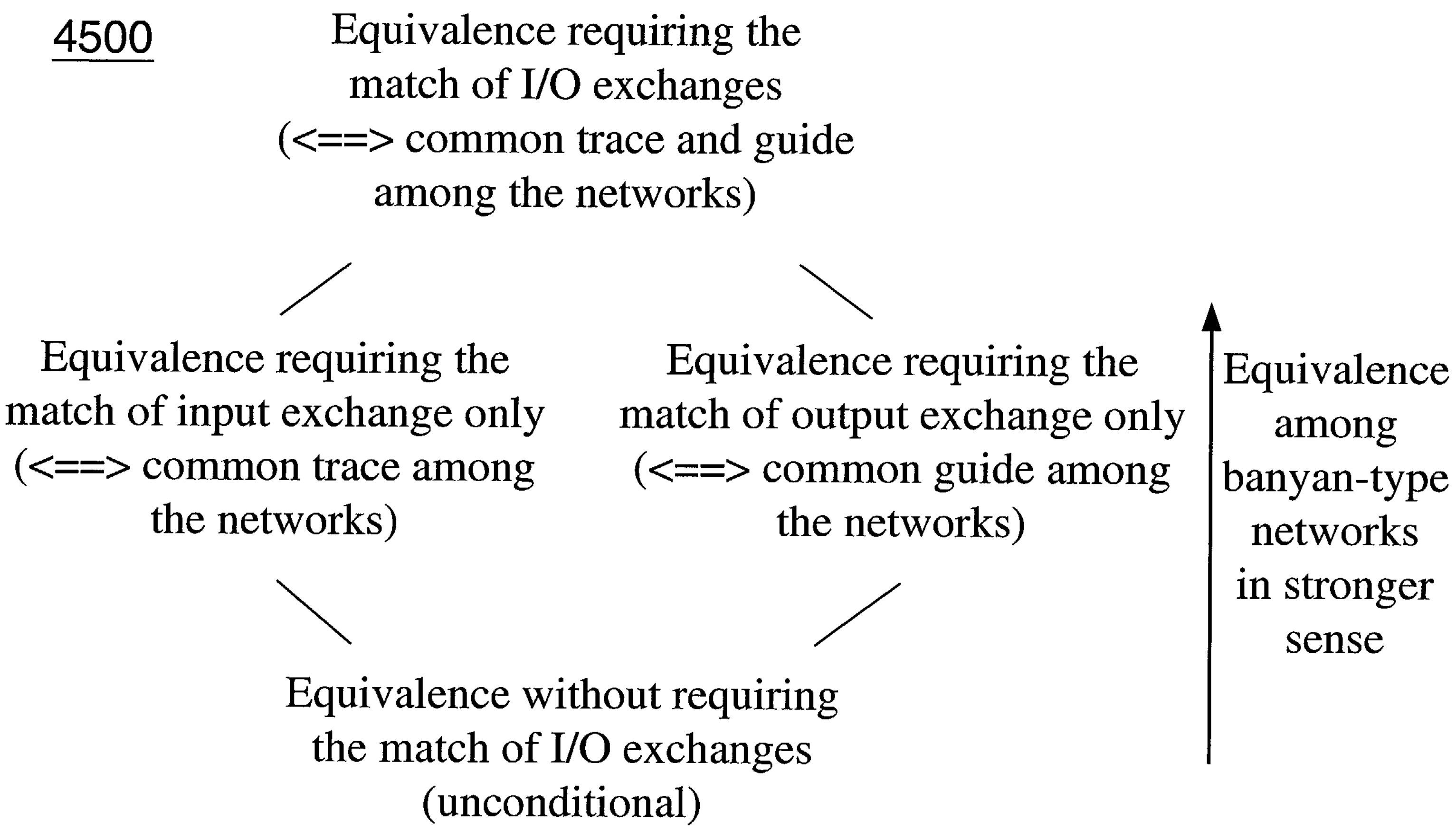

4500
Equivalence requiring the match of I/O exchanges (<==> common trace and guide among the networks)
Equivalence requiring the match of input exchange only (<==> common trace among the networks)
Equivalence requiring the match of output exchange only (<==> common guide among the networks)
Equivalence without requiring the match of I/O exchanges (unconditional)
Equivalence among banyan-type networks in stronger sense

FIG. 45

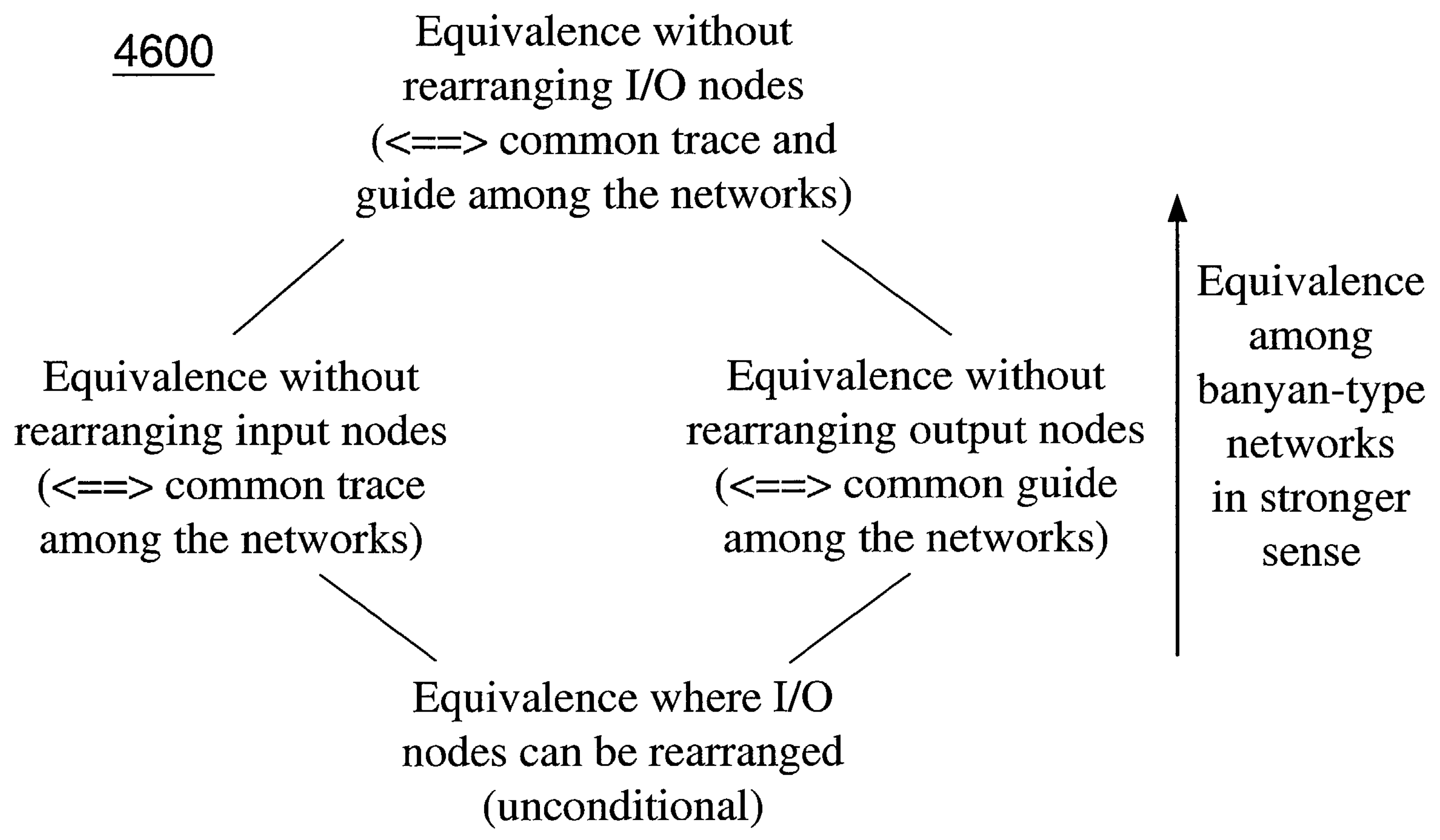

4600
Equivalence without rearranging I/O nodes (<==> common trace and guide among the networks)
Equivalence without rearranging input nodes (<==> common trace among the networks)
Equivalence without rearranging output nodes (<==> common guide among the networks)
Equivalence where I/O nodes can be rearranged (unconditional)
Equivalence among banyan-type networks in stronger sense

FIG. 46

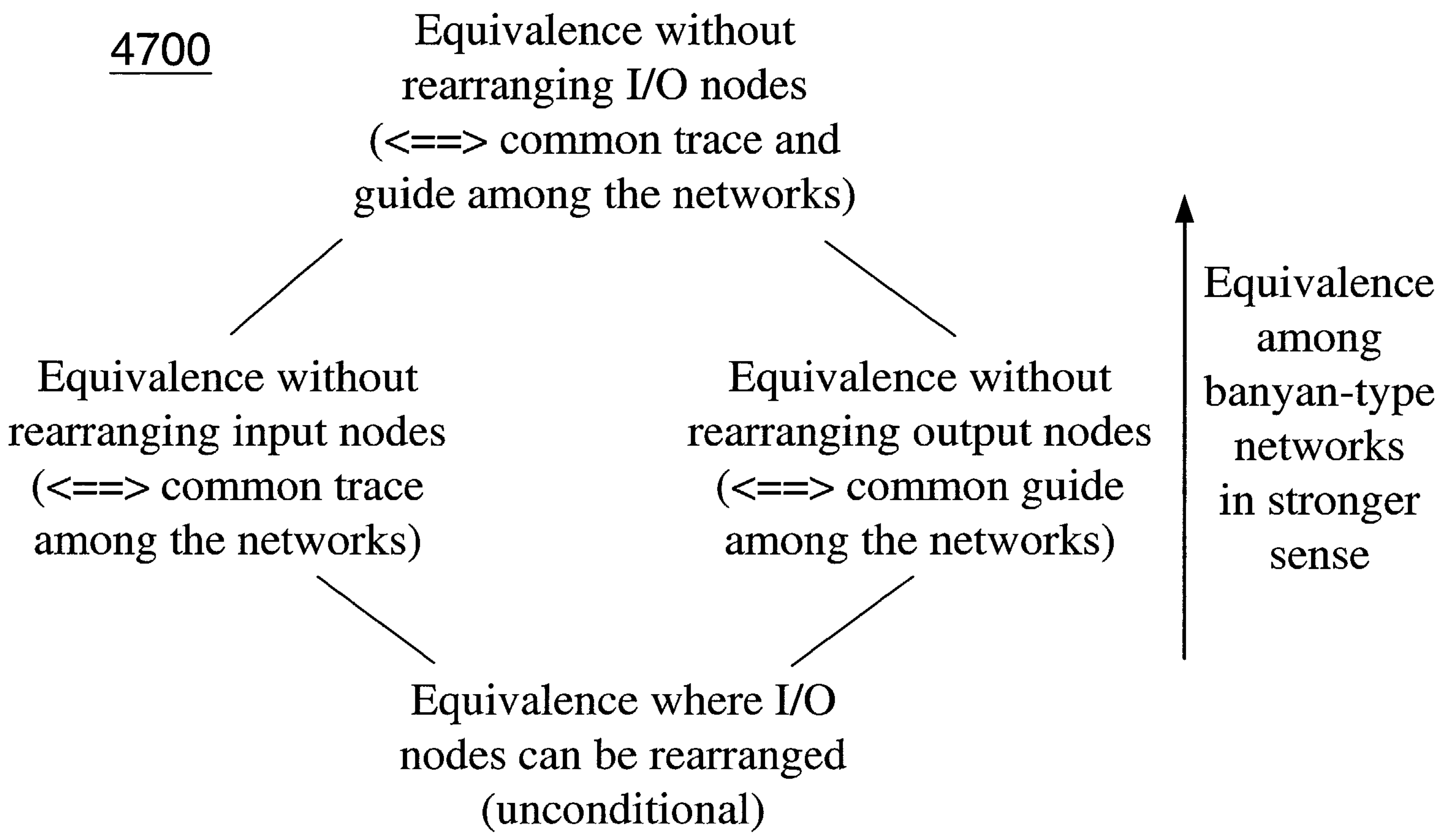

4700
Equivalence without rearranging I/O nodes (<==> common trace and guide among the networks)
Equivalence without rearranging input nodes (<==> common trace among the networks)
Equivalence without rearranging output nodes (<==> common guide among the networks)
Equivalence where I/O nodes can be rearranged (unconditional)
Equivalence among banyan-type networks in stronger sense

FIG. 47

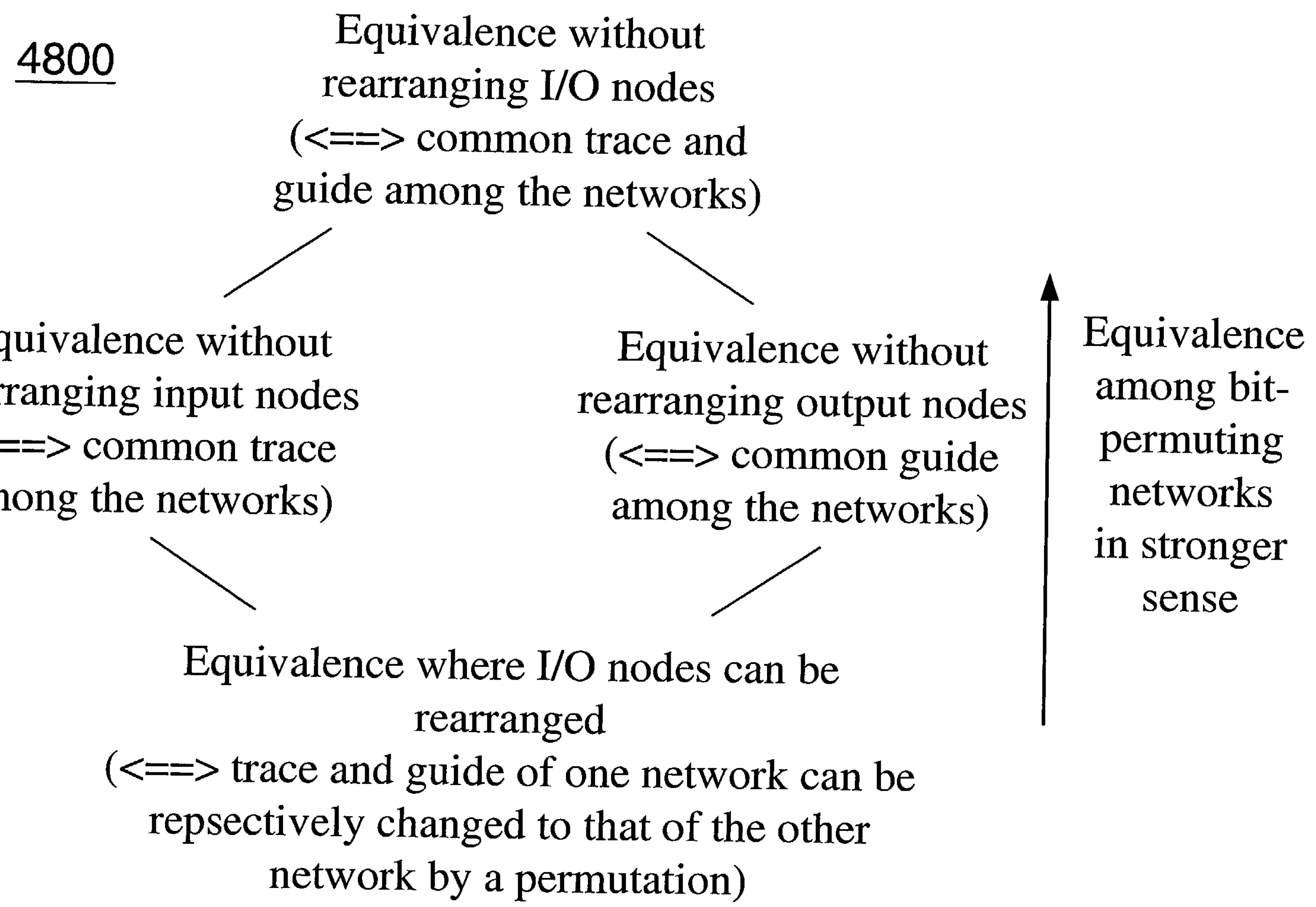

4800
Equivalence without rearranging I/O nodes (<==> common trace and guide among the networks)
Equivalence without rearranging input nodes (<==> common trace among the networks)
Equivalence without rearranging output nodes (<==> common guide among the networks)
Equivalence where I/O nodes can be rearranged (<==> trace and guide of one network can be repsectively changed to that of the other network by a permutation)
Equivalence among bit-permuting networks in stronger sense

FIG. 48

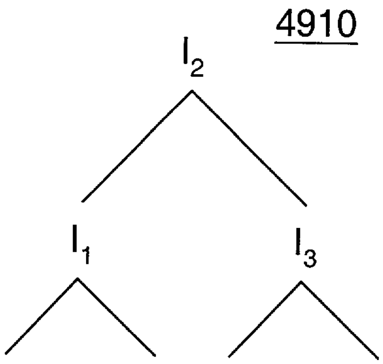


FIG. 49A

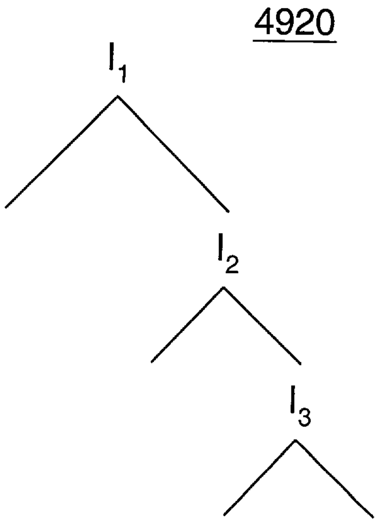


FIG. 49B

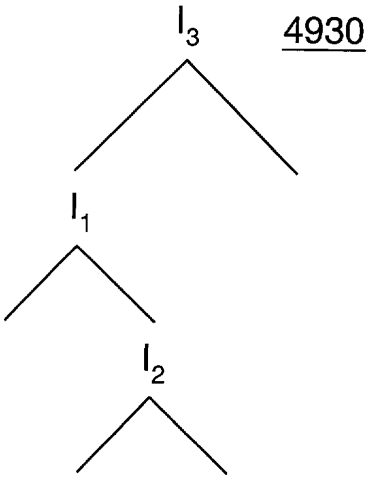


FIG. 49C

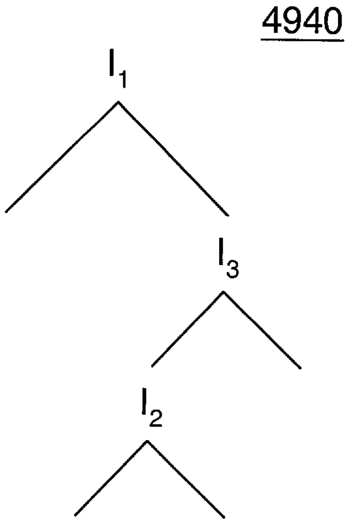


FIG. 49D

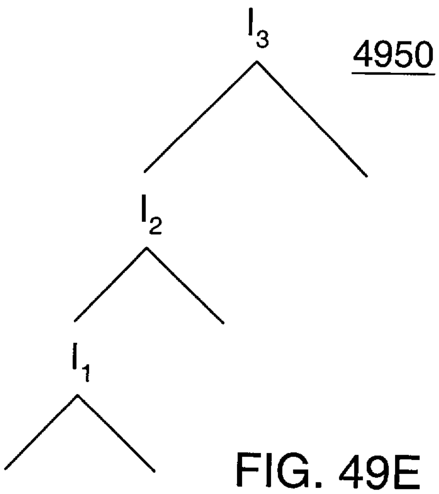


FIG. 49E

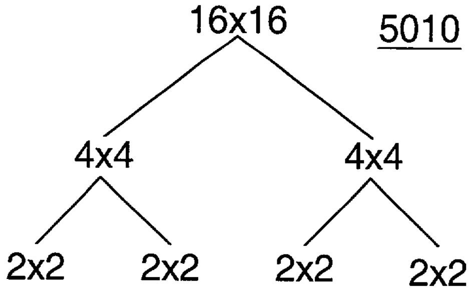


FIG. 50A

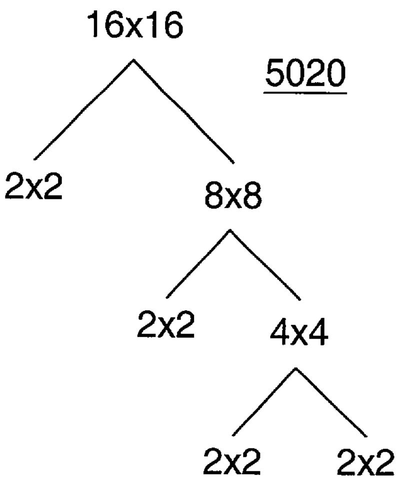


FIG. 50B

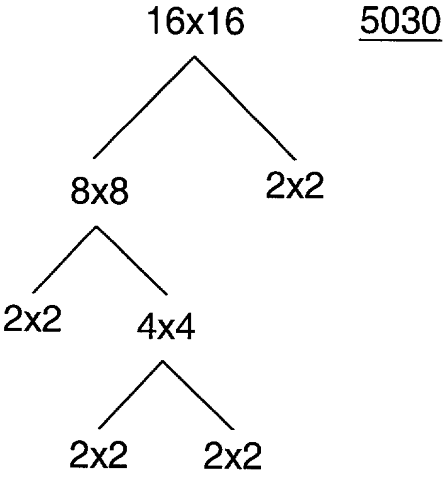


FIG. 50C

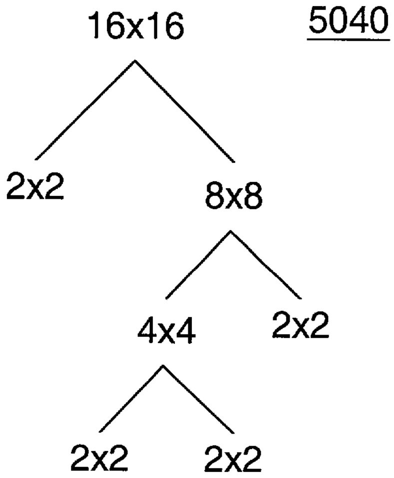


FIG. 50D

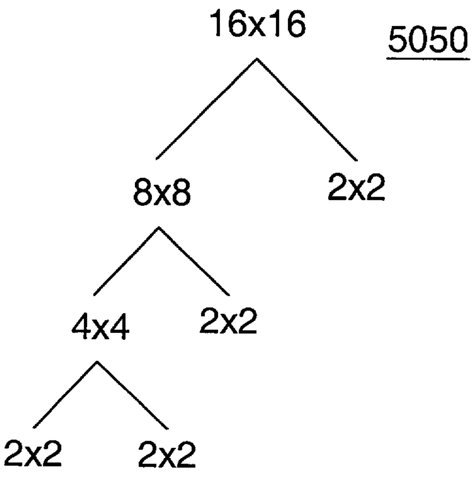


FIG. 50E

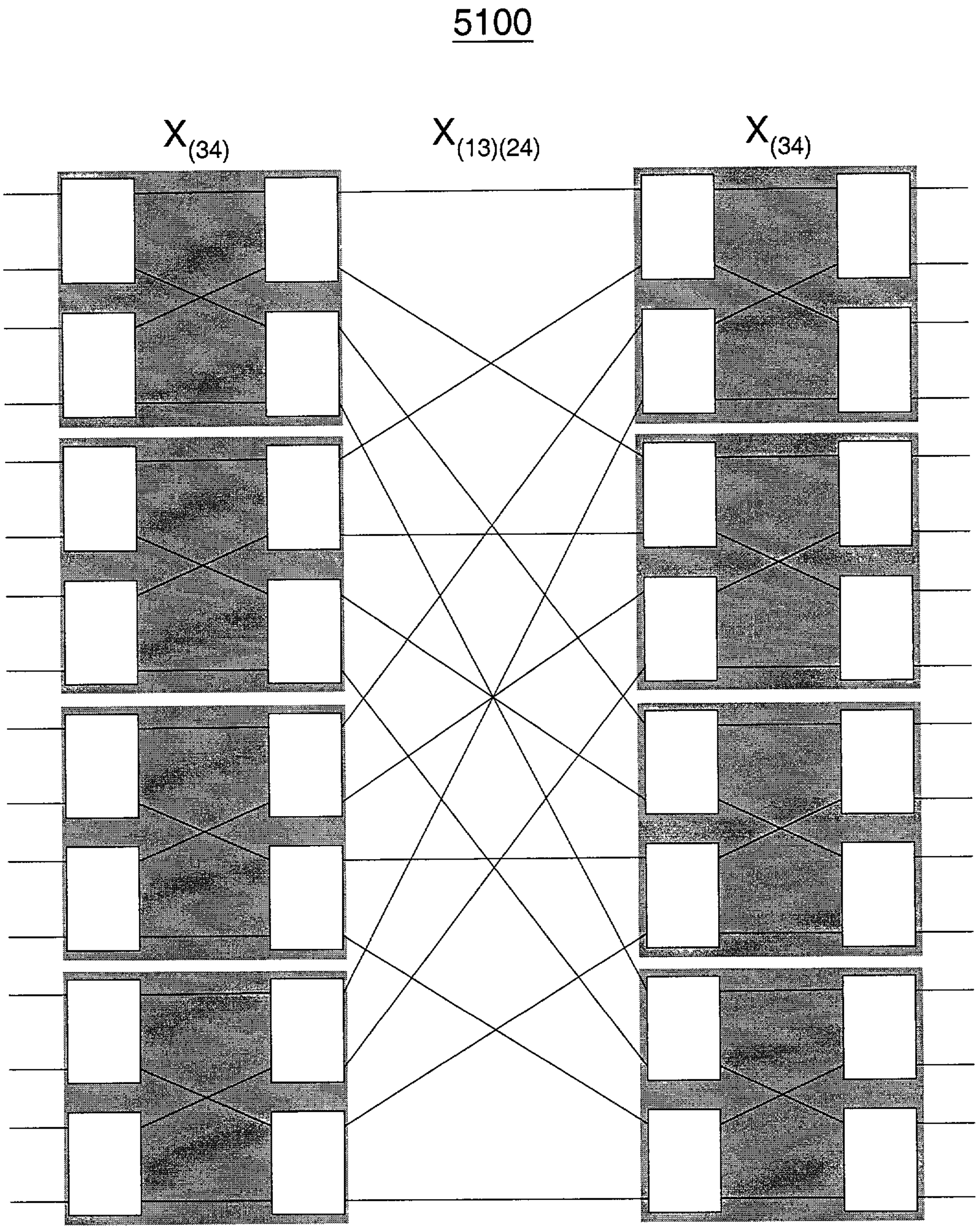


FIG. 51

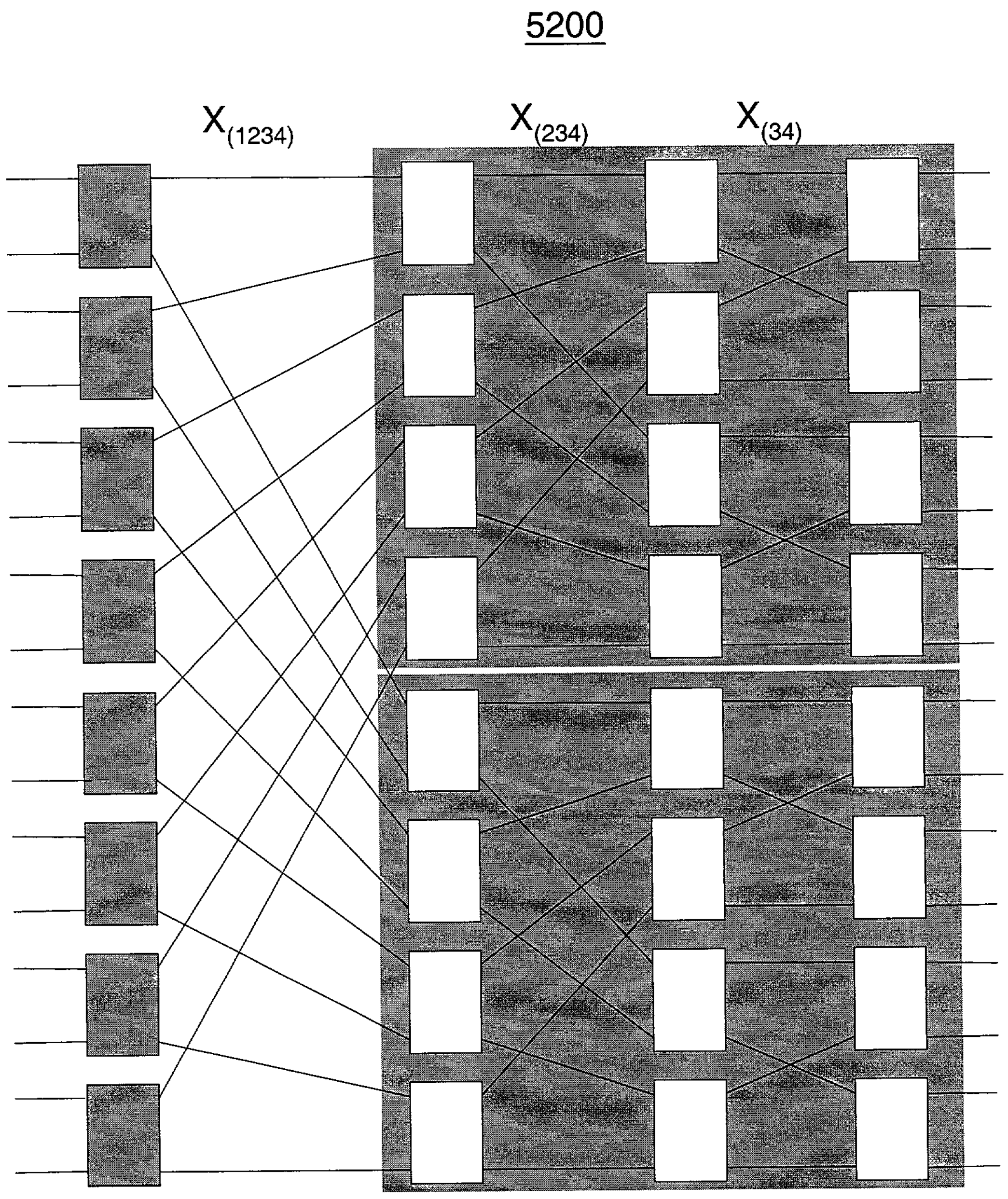
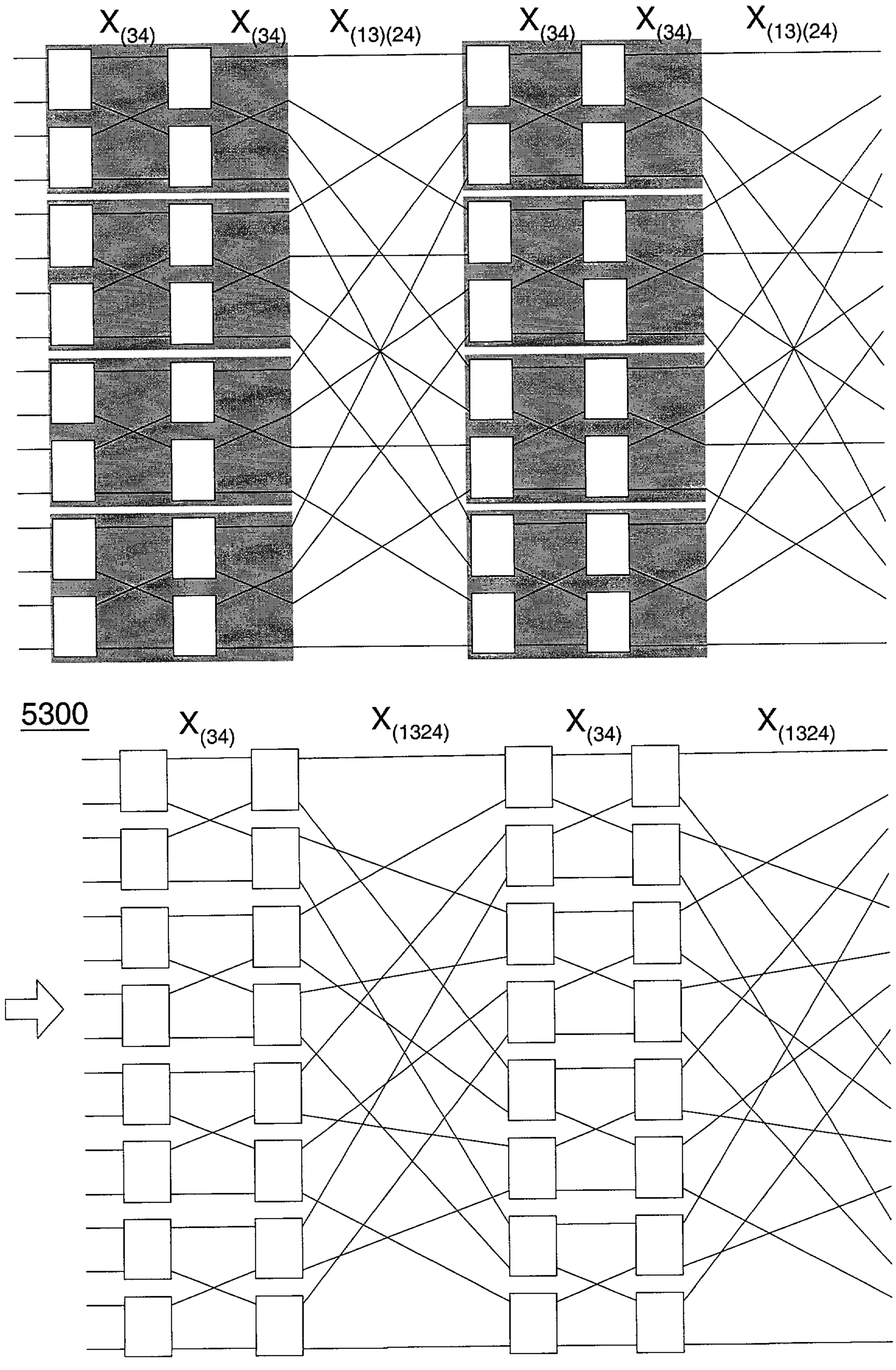


FIG. 52

FIG. 53



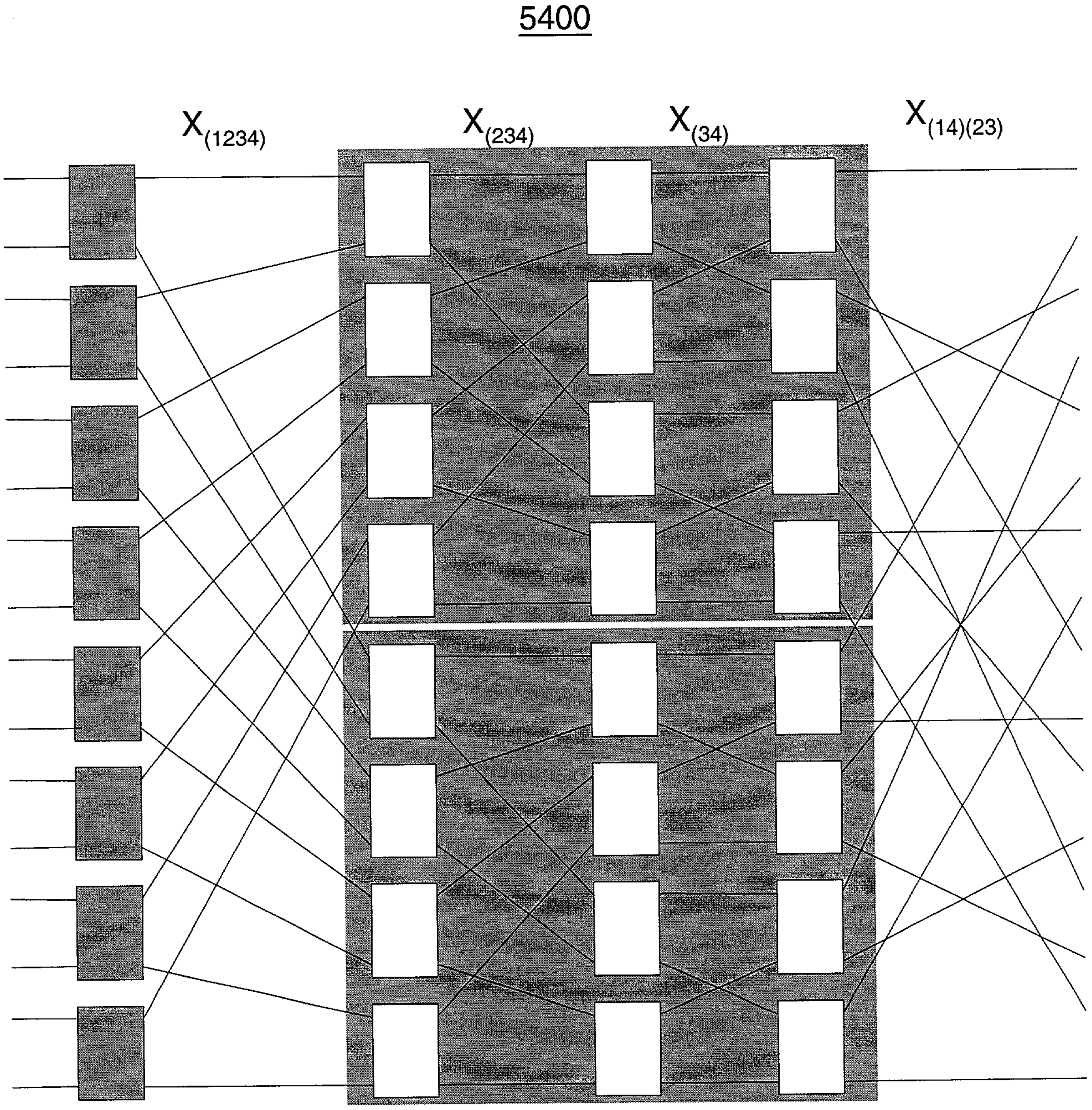


FIG. 54

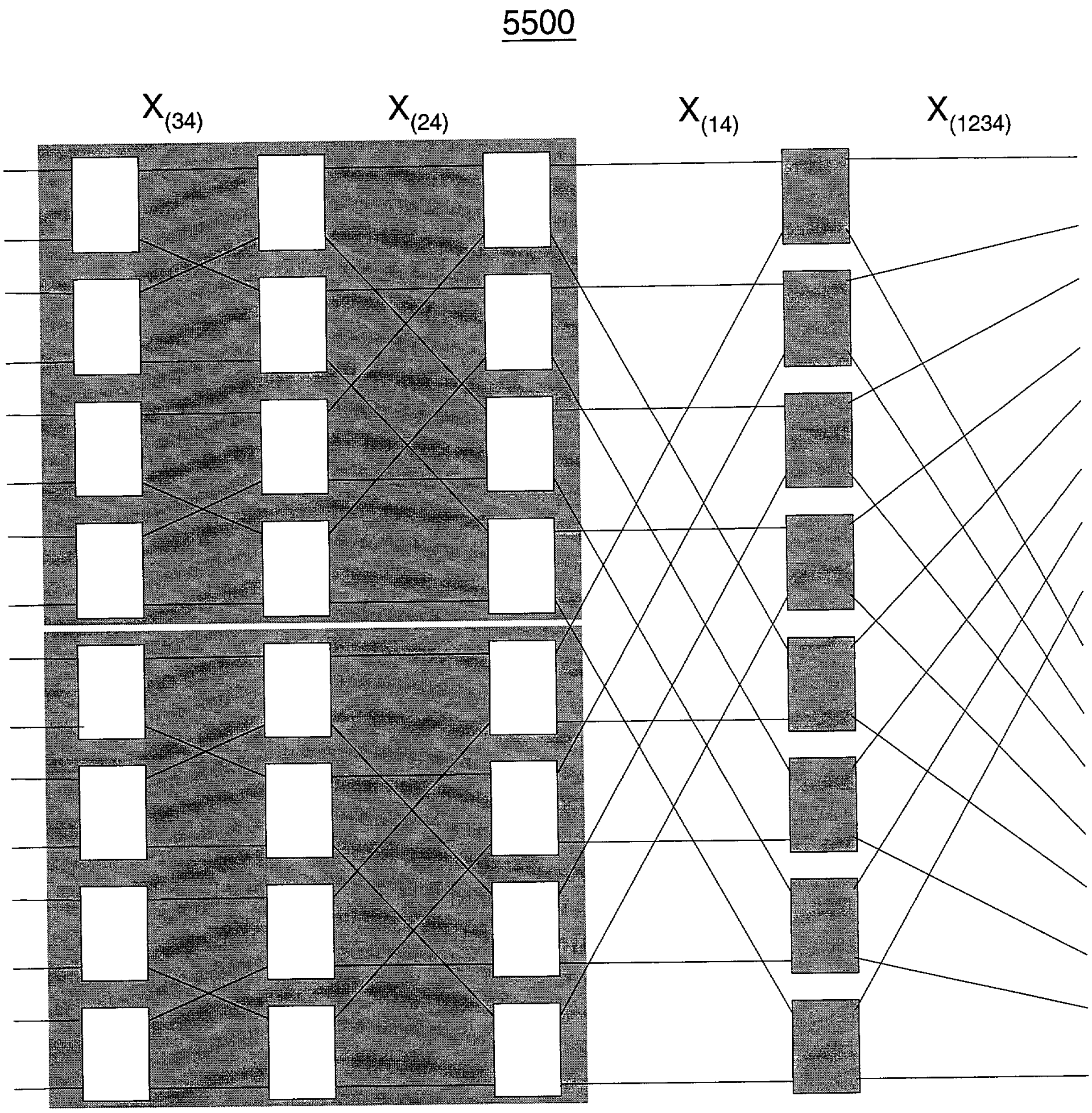


FIG. 55

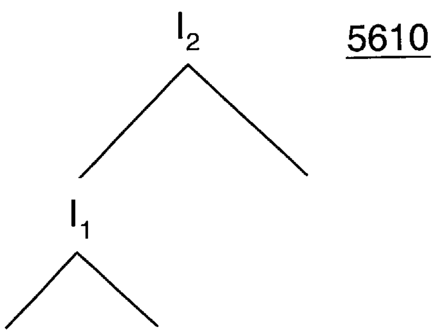


FIG. 56A

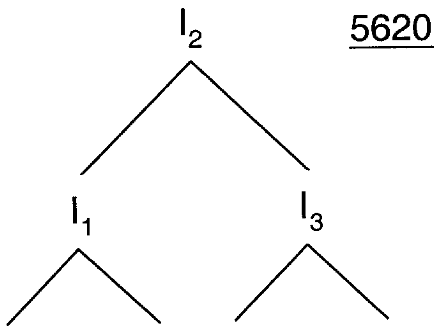


FIG. 56B

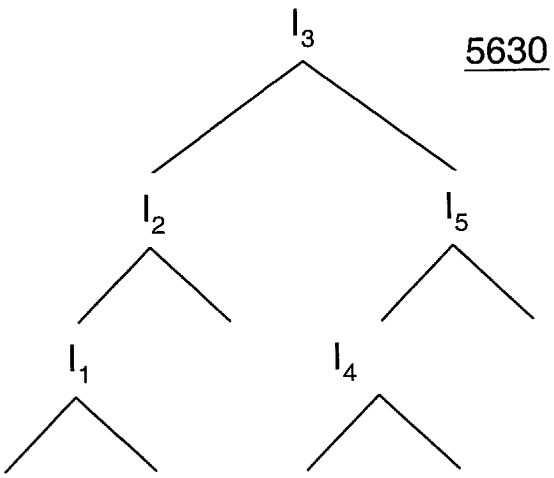


FIG. 56C

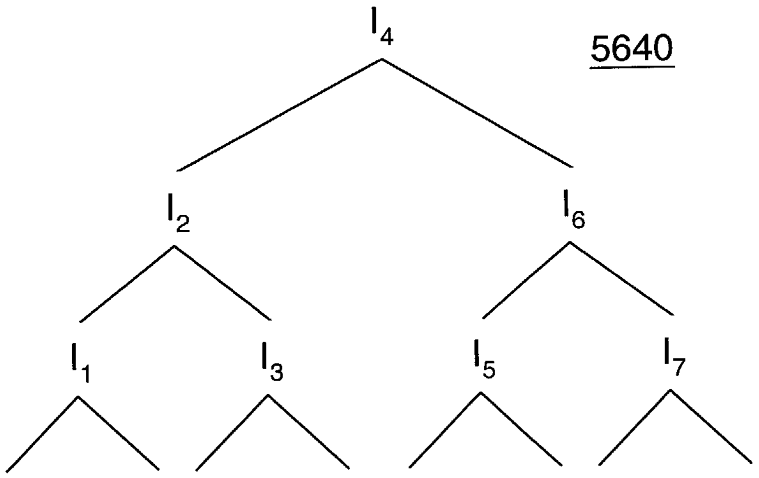


FIG. 56D

FIG. 57

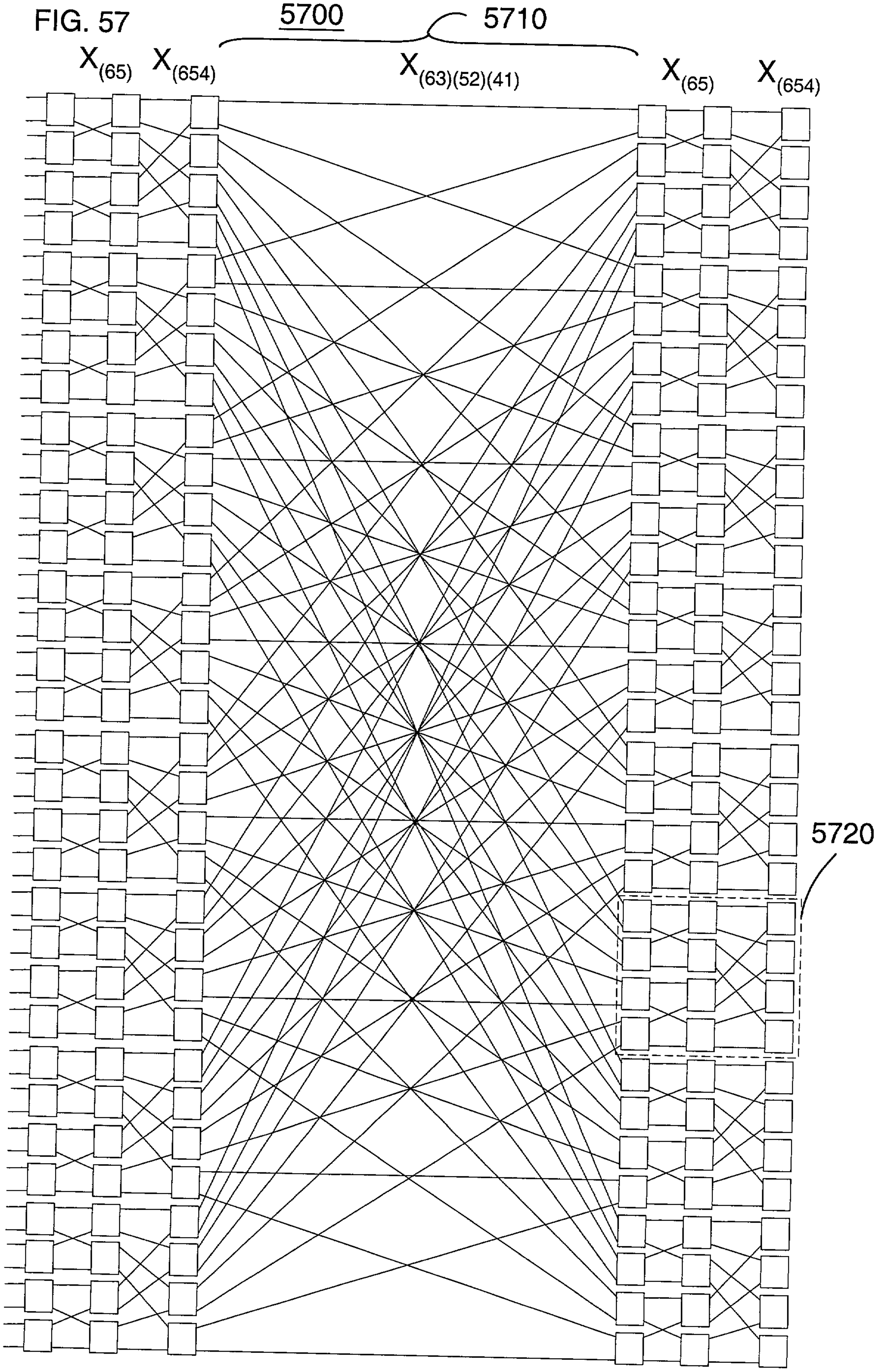


FIG. 58

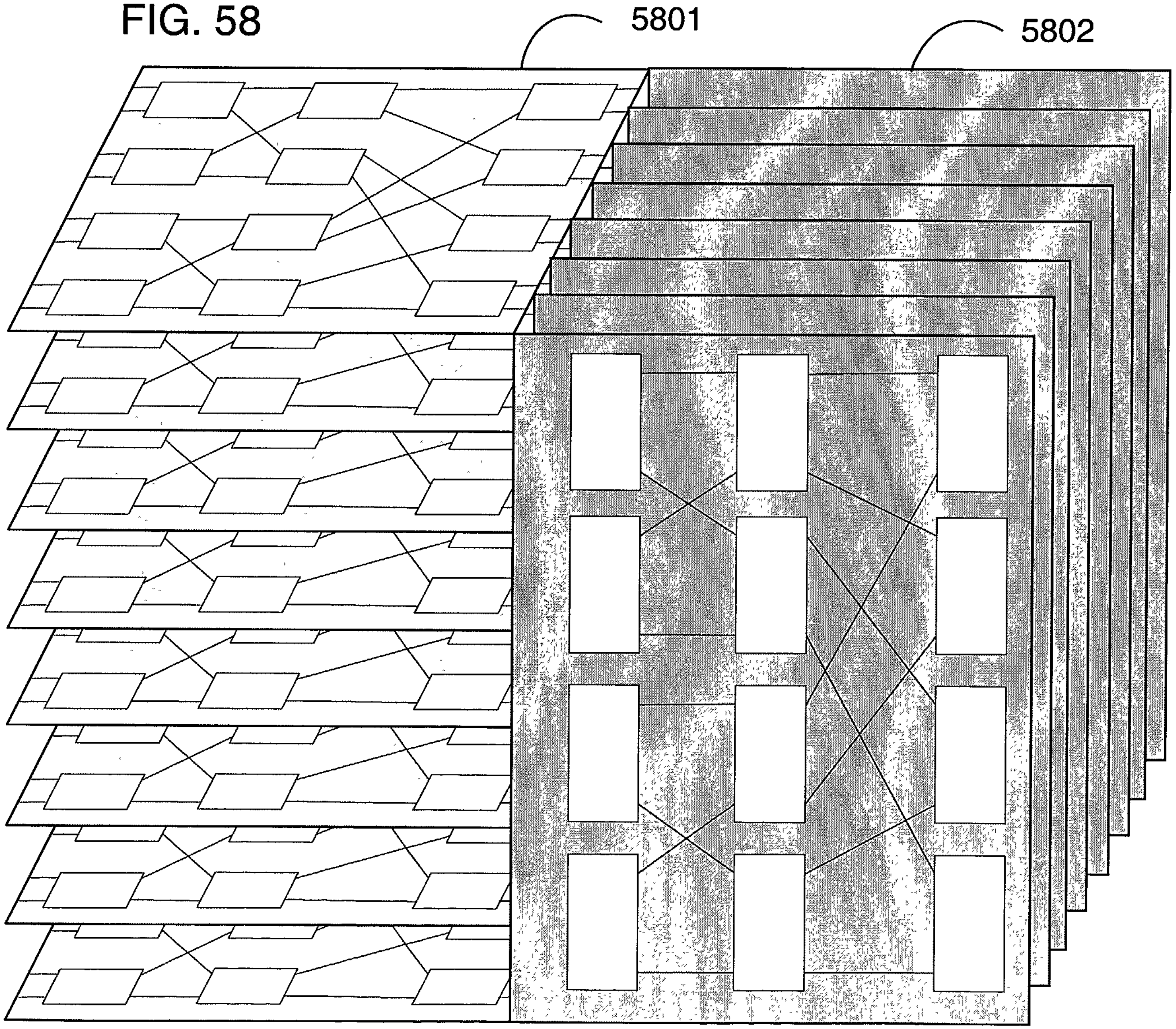
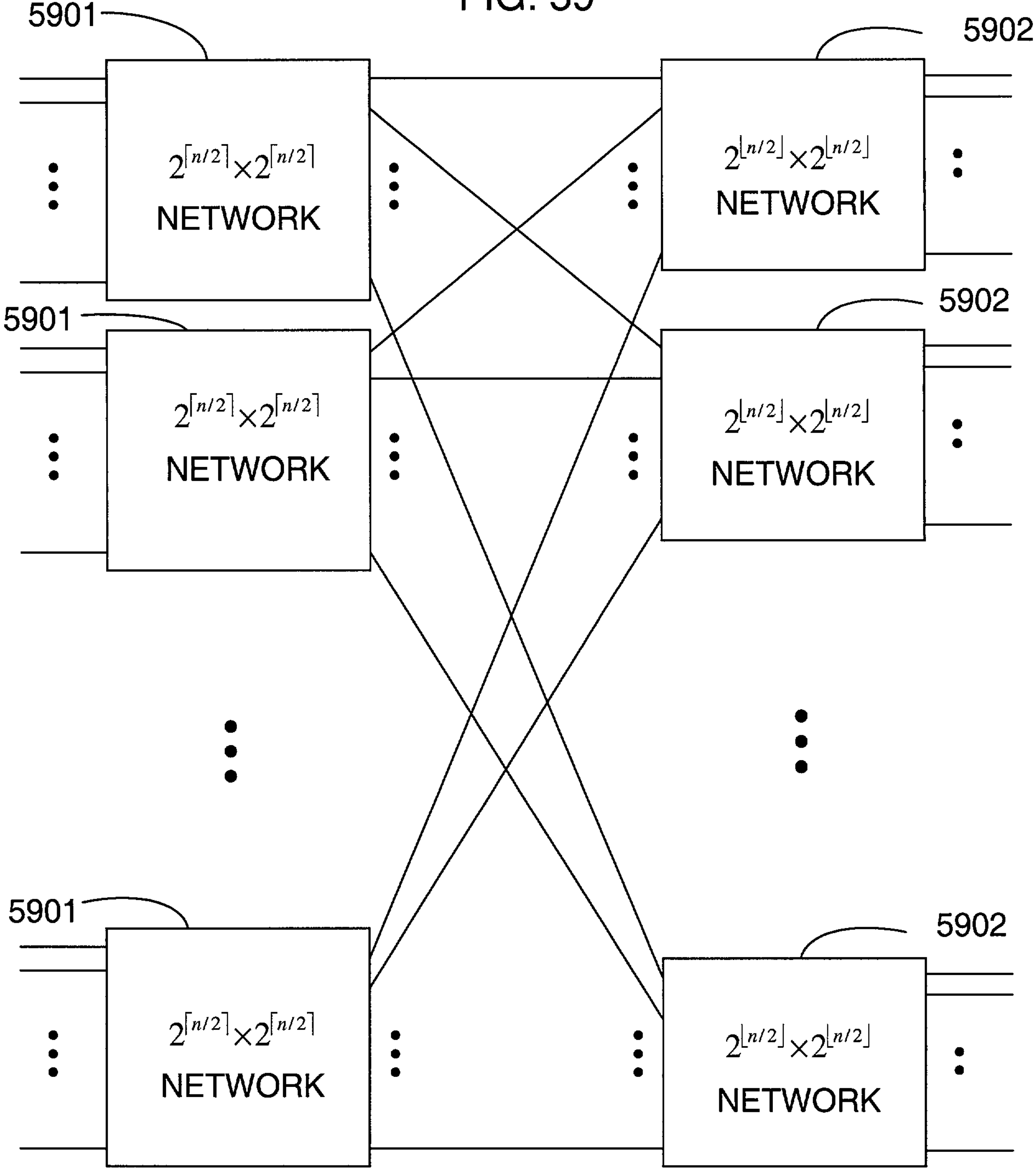


FIG. 59


5901
$2^{\lceil n/2 \rceil} \times 2^{\lceil n/2 \rceil}$ NETWORK
5901
$2^{\lceil n/2 \rceil} \times 2^{\lceil n/2 \rceil}$ NETWORK
5901
$2^{\lceil n/2 \rceil} \times 2^{\lceil n/2 \rceil}$ NETWORK
5902
$2^{\lfloor n/2 \rfloor} \times 2^{\lfloor n/2 \rfloor}$ NETWORK
5902
$2^{\lfloor n/2 \rfloor} \times 2^{\lfloor n/2 \rfloor}$ NETWORK
5902
$2^{\lfloor n/2 \rfloor} \times 2^{\lfloor n/2 \rfloor}$ NETWORK

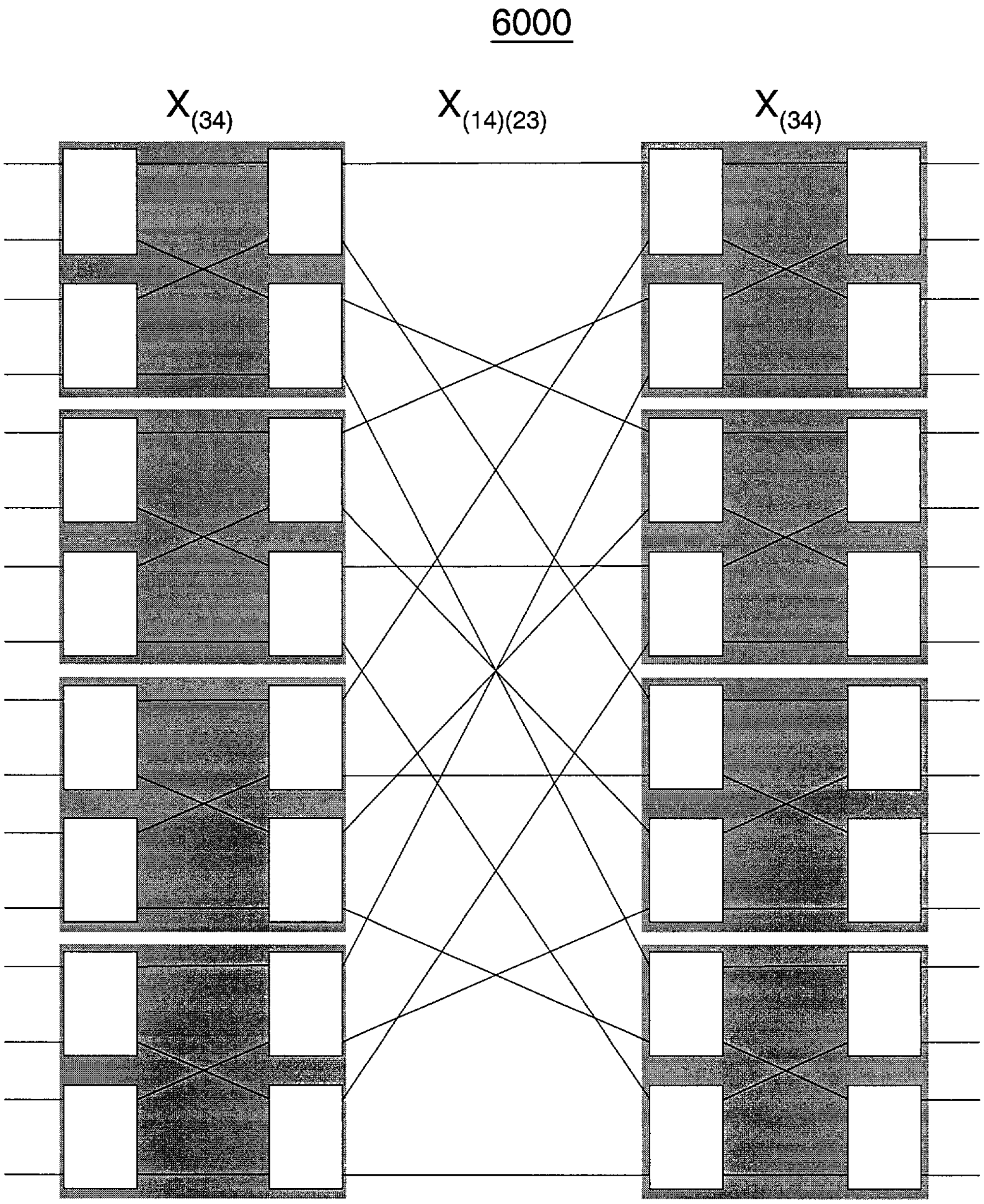
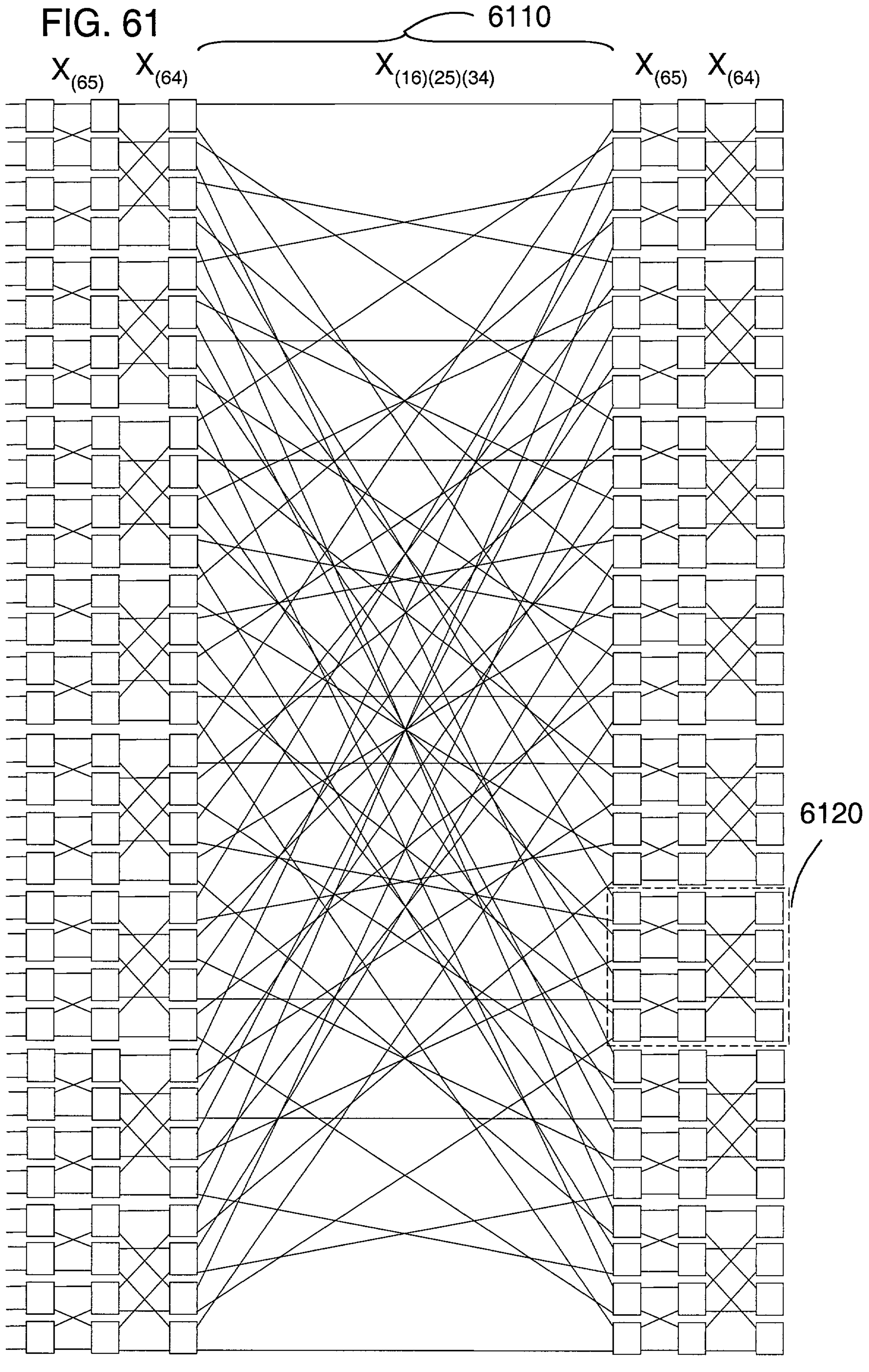


FIG. 60

FIG. 61



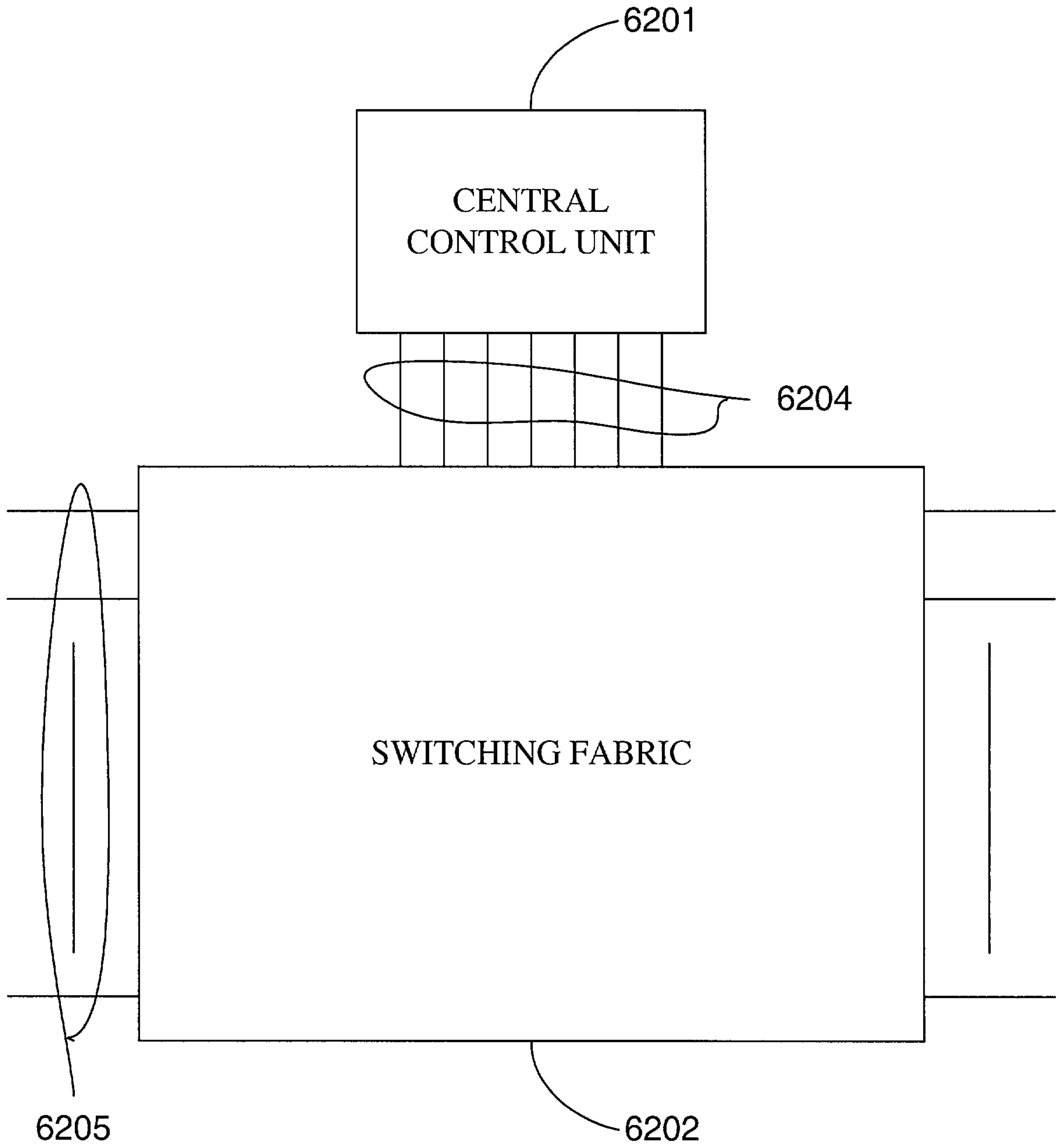


FIG. 62A

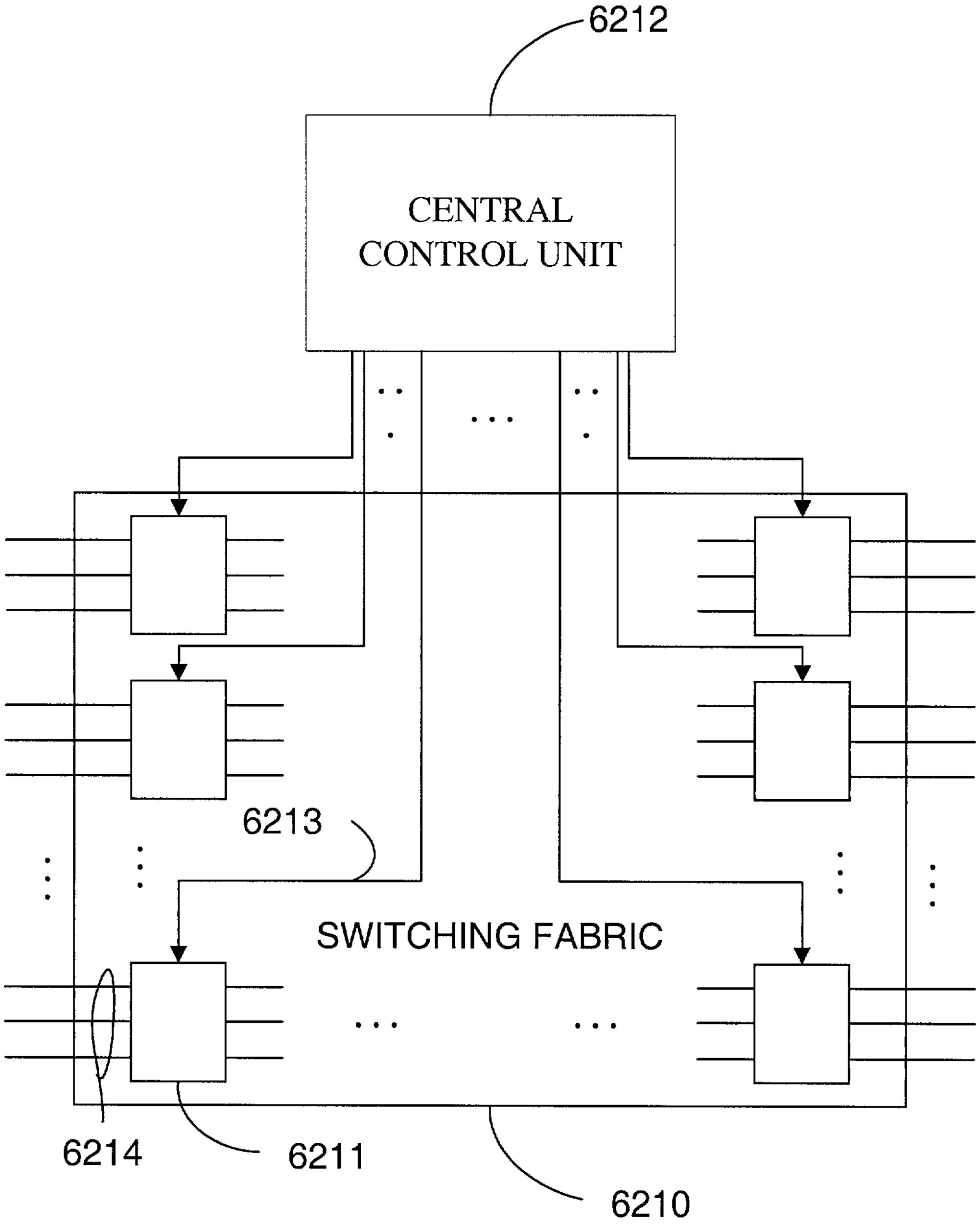

6212
CENTRAL CONTROL UNIT
6213
SWITCHING FABRIC
6214
6211
6210

FIG. 62B

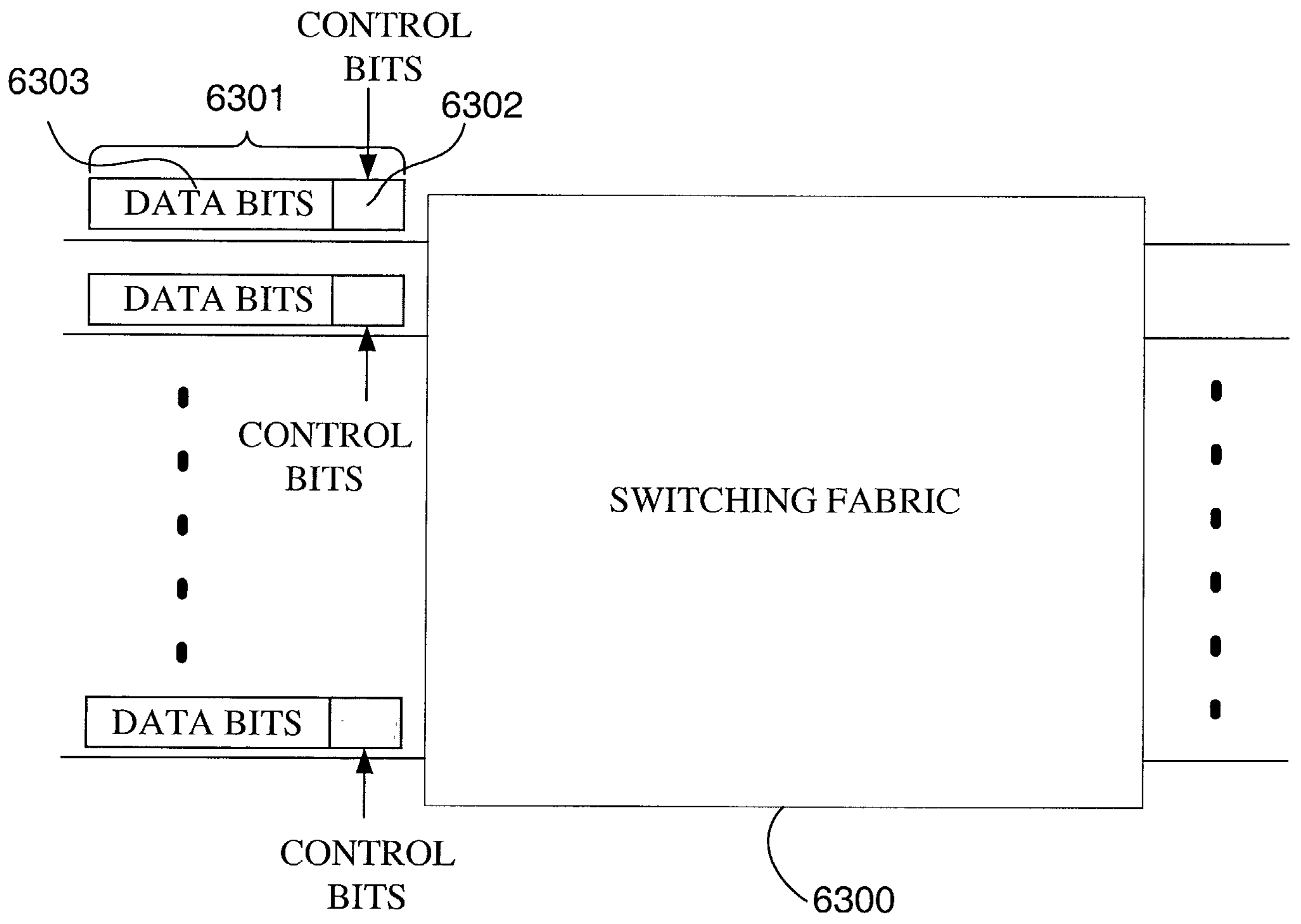

CONTROL BITS
6303
6301
6302
DATA BITS
DATA BITS
CONTROL BITS
DATA BITS
CONTROL BITS
SWITCHING FABRIC
6300

FIG. 63A

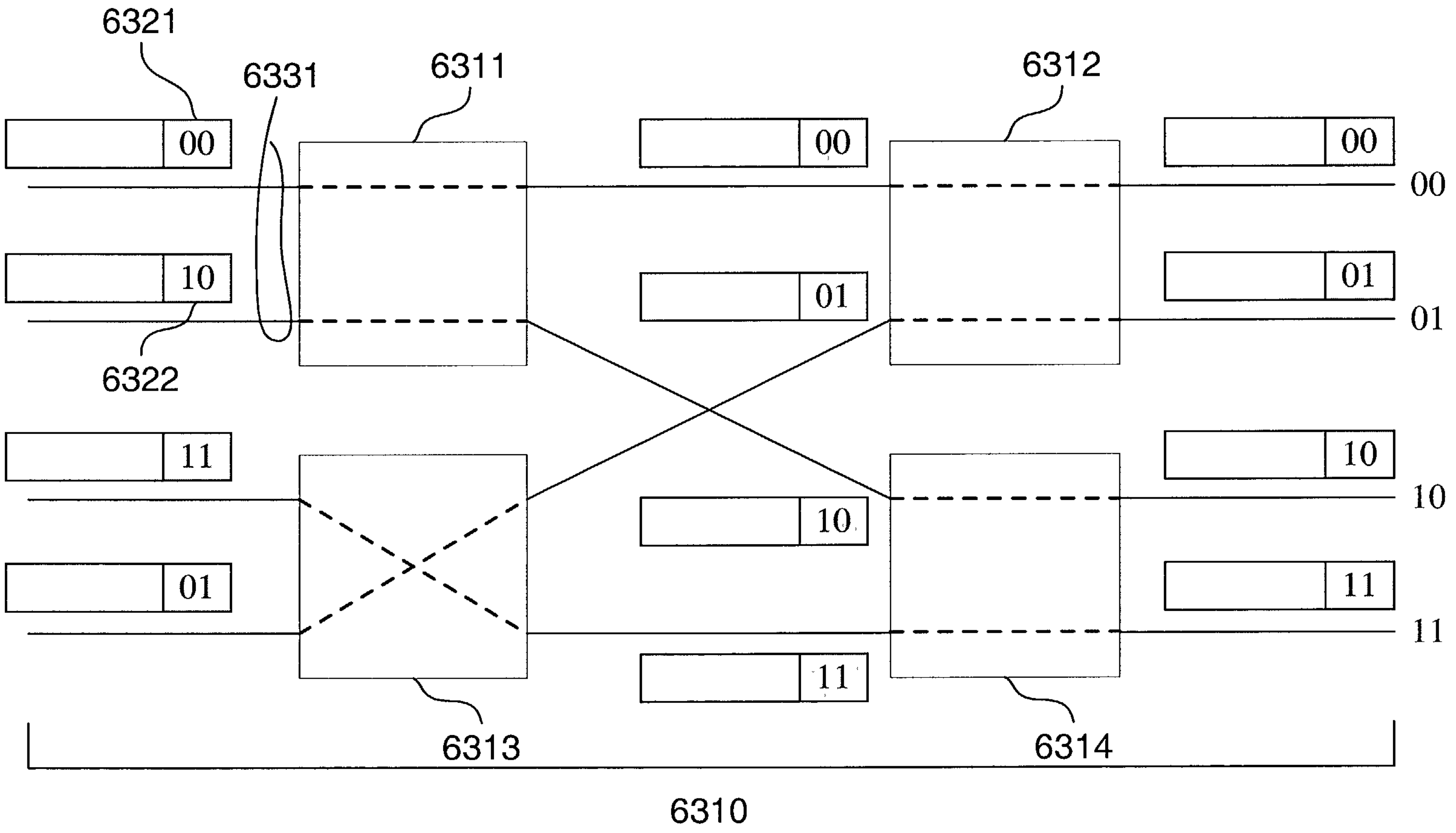

6321
6331
6311
6312
6322
6313
6314
6310
00
10
11
01
00
01
10
11
00
01
10
11
00
01
10
11

FIG. 63B

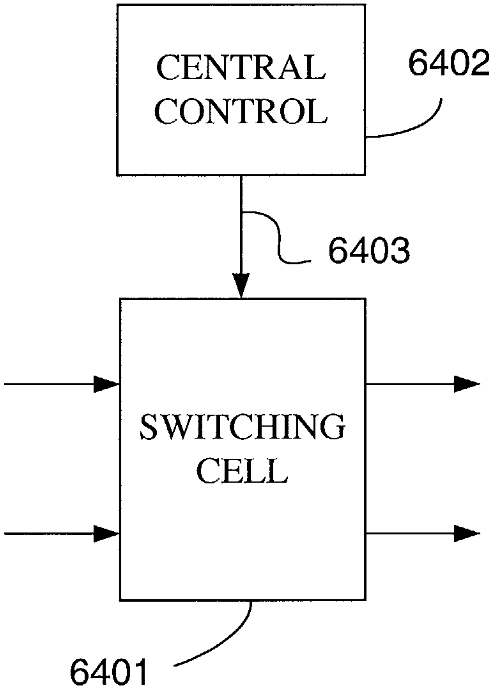


FIG. 64A

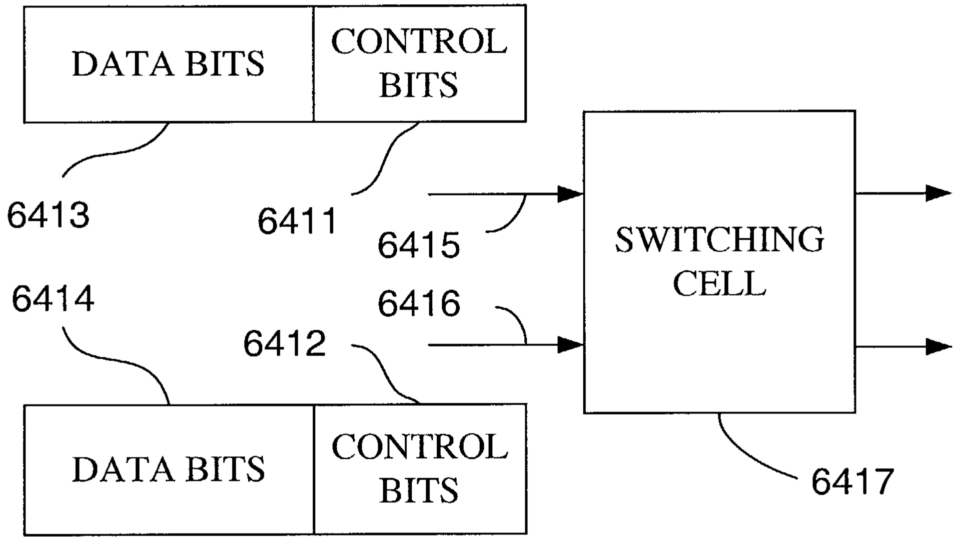


FIG. 64B

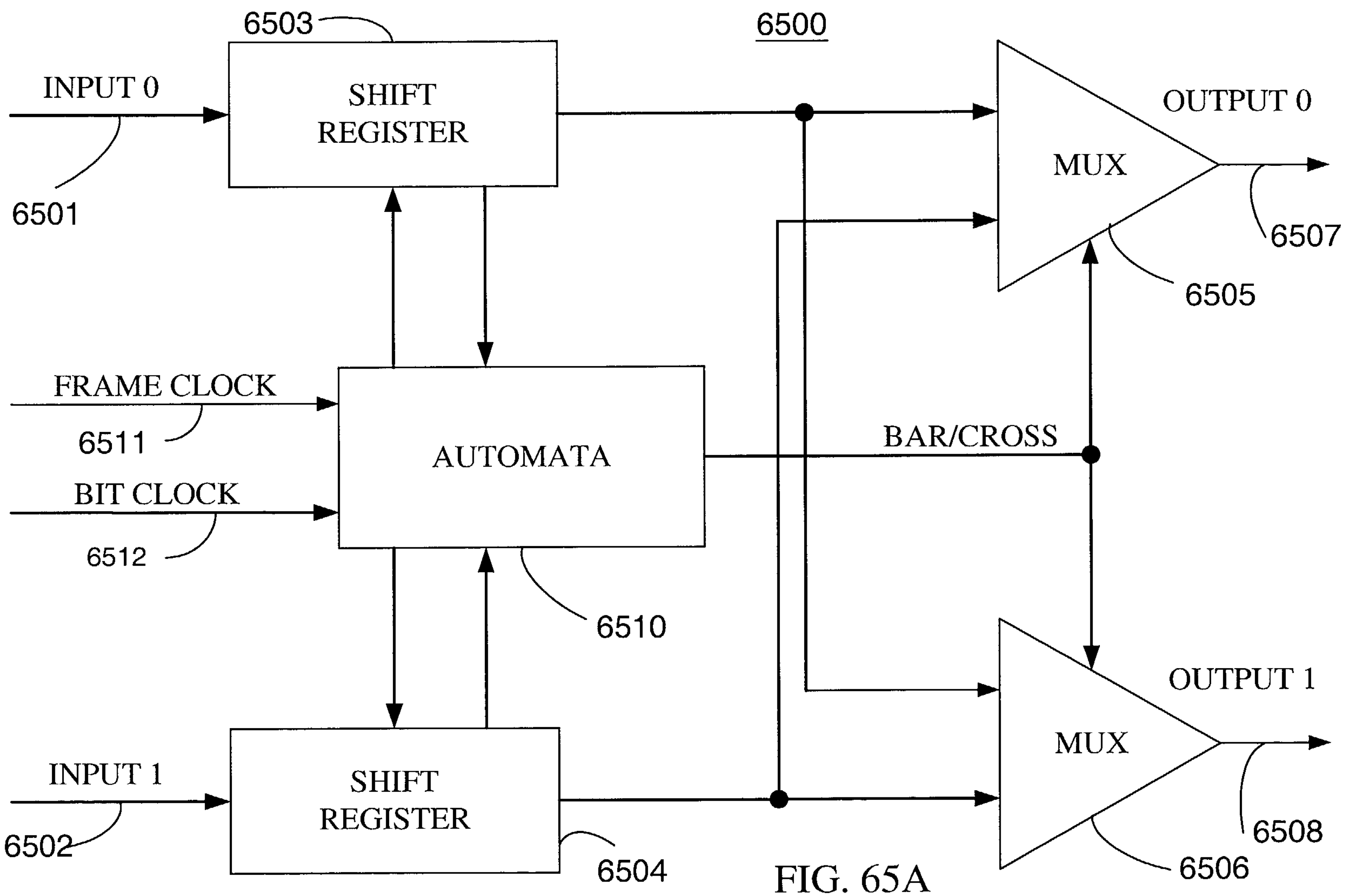

6500
6503
INPUT 0
6501
SHIFT REGISTER
FRAME CLOCK
6511
BIT CLOCK
6512
AUTOMATA
6510
INPUT 1
6502
SHIFT REGISTER
6504
BAR/CROSS
MUX
OUTPUT 0
6505
6507
MUX
OUTPUT 1
6506
6508

FIG. 65A

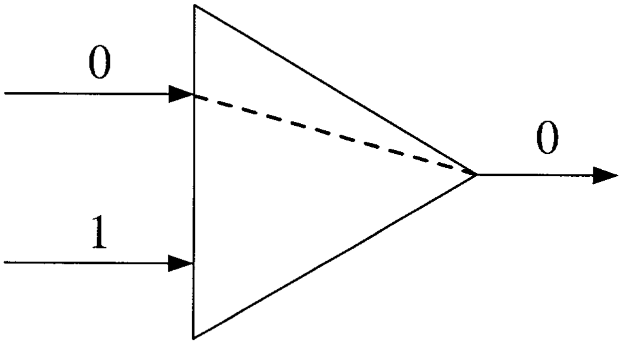


FIG. 65B

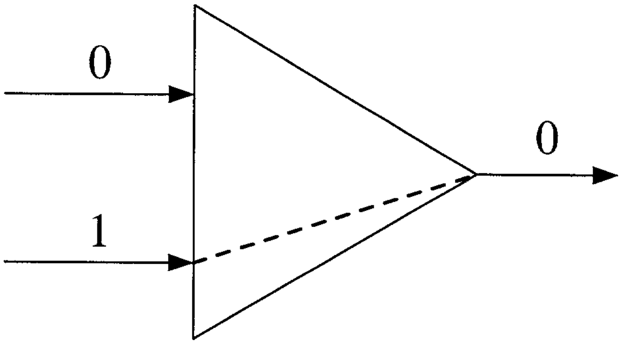


FIG. 65C

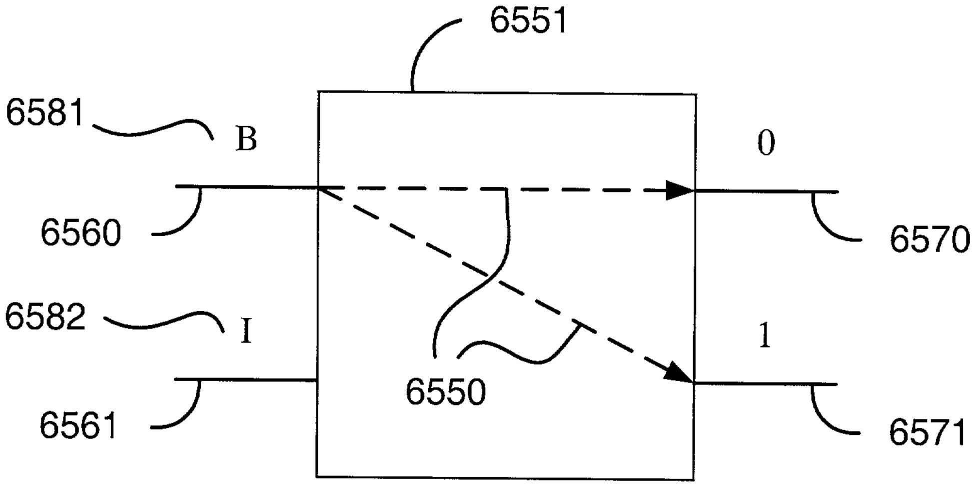


FIG. 65D

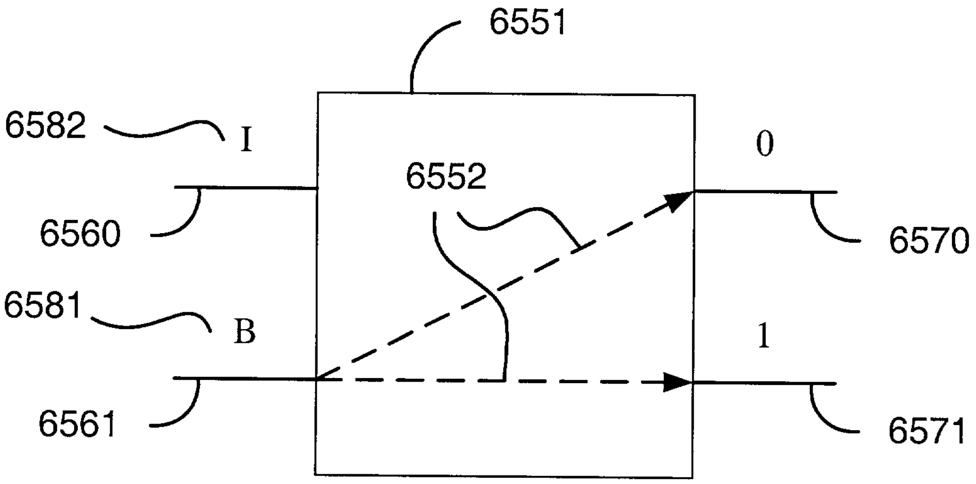


FIG. 65E

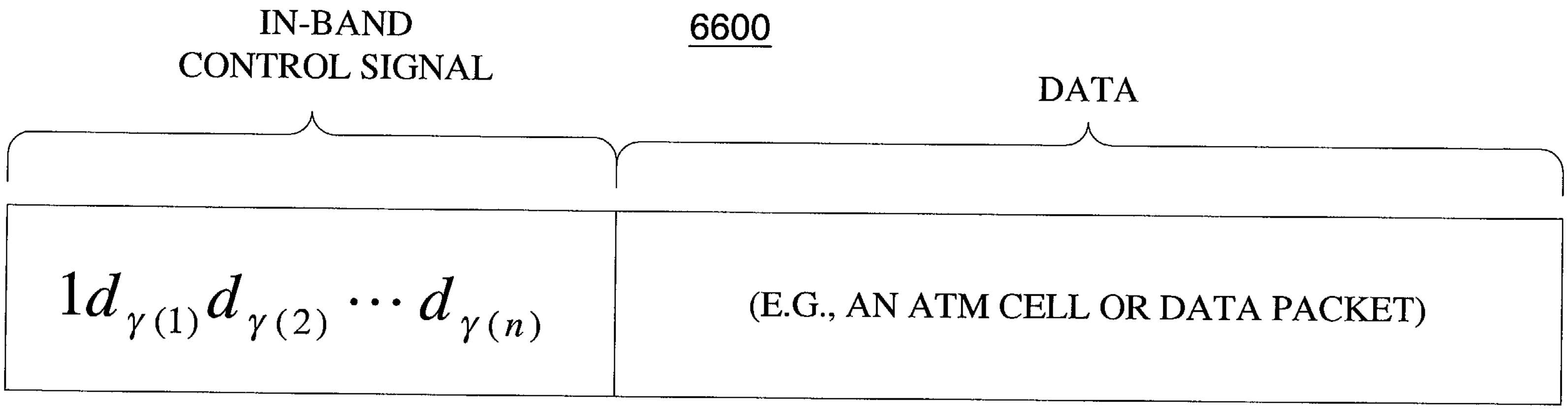

IN-BAND
CONTROL SIGNAL
6600
DATA
$1d_{\gamma(1)}d_{\gamma(2)}\cdots d_{\gamma(n)}$
(E.G., AN ATM CELL OR DATA PACKET)

FIG. 66A

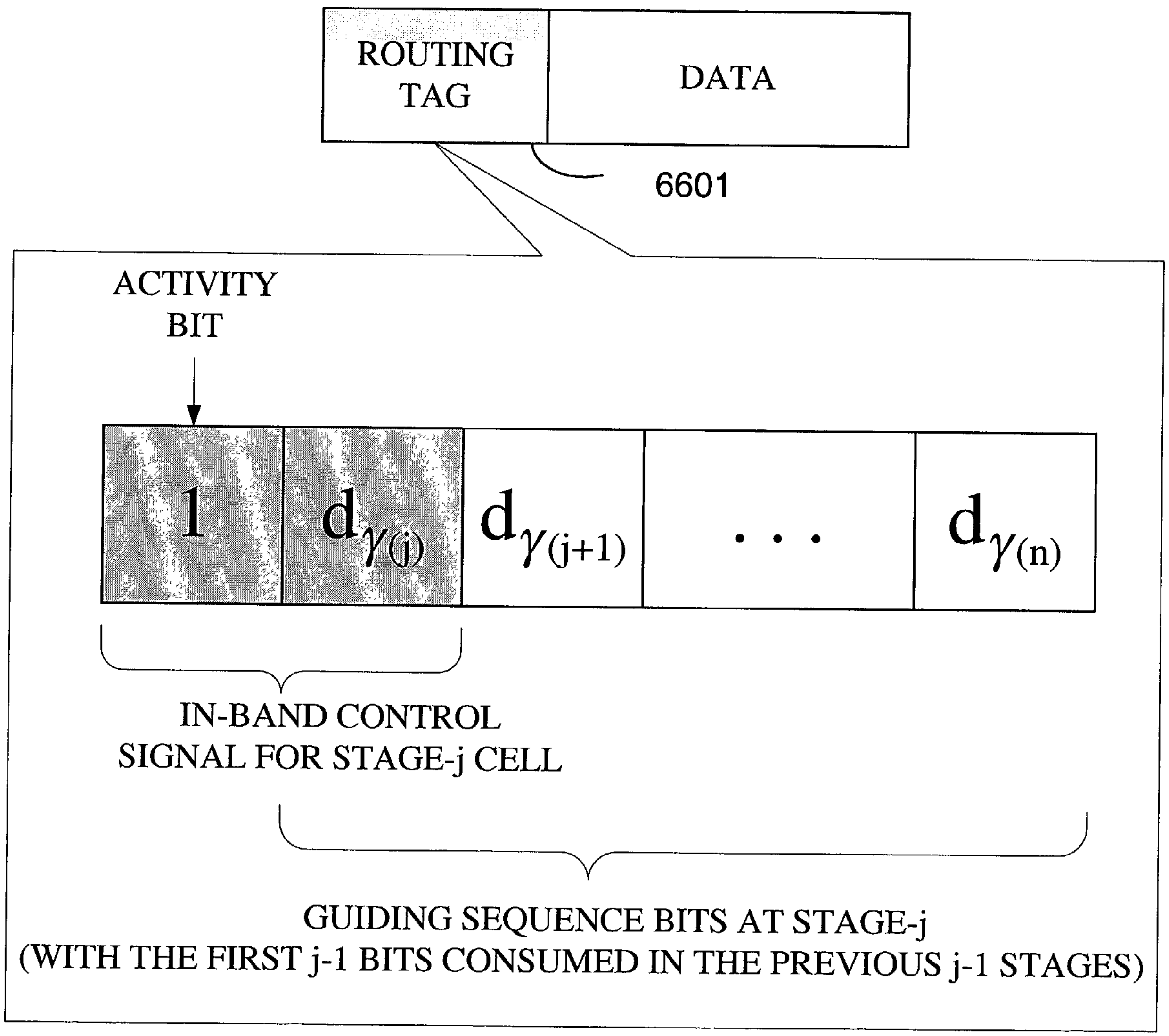

ROUTING TAG
DATA
6601
ACTIVITY BIT
1
$d_{\gamma(j)}$
$d_{\gamma(j+1)}$
. . .
$d_{\gamma(n)}$
IN-BAND CONTROL SIGNAL FOR STAGE-j CELL
GUIDING SEQUENCE BITS AT STAGE-j
(WITH THE FIRST j-1 BITS CONSUMED IN THE PREVIOUS j-1 STAGES)

FIG. 66B

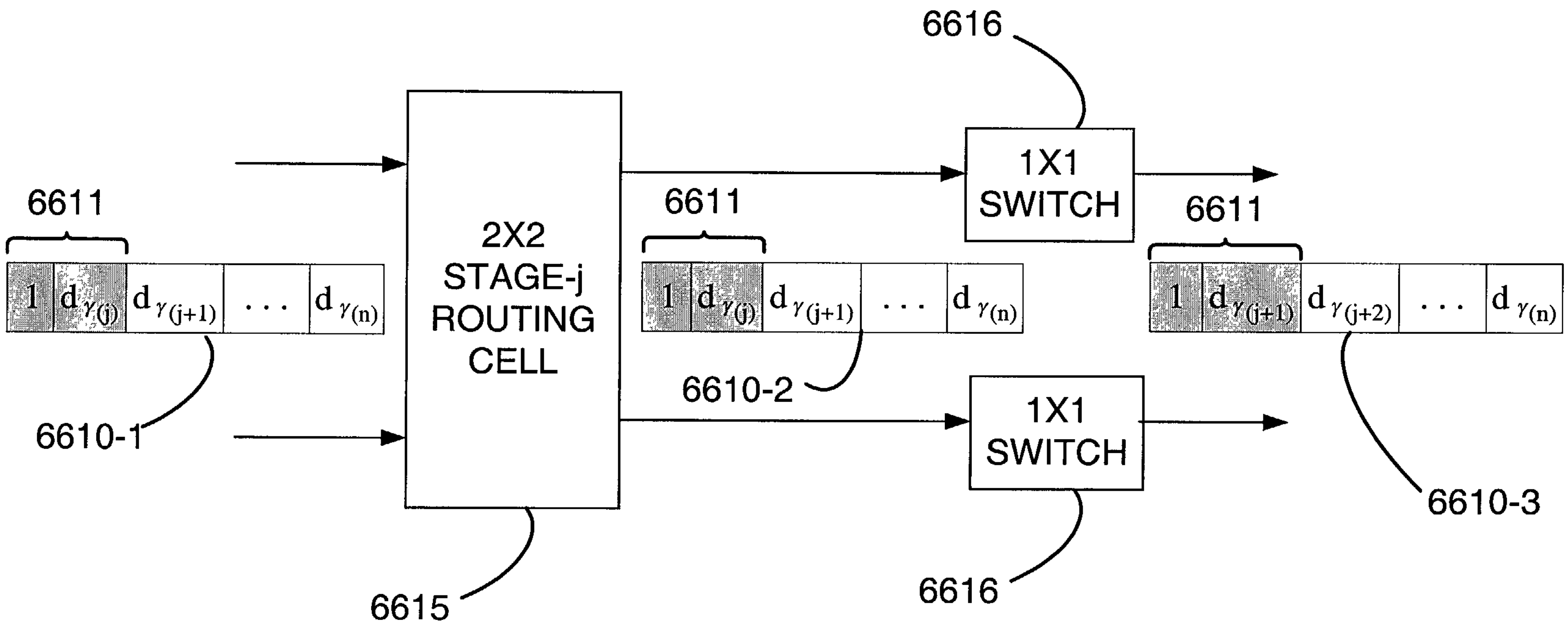

6611
1
$d_{\gamma(j)}$
$d_{\gamma(j+1)}$
. . .
$d_{\gamma(n)}$
6610-1
2X2
STAGE-j
ROUTING
CELL
6615
6611
1
$d_{\gamma(j)}$
$d_{\gamma(j+1)}$
. . .
$d_{\gamma(n)}$
6610-2
6616
1X1
SWITCH
1X1
SWITCH
6616
6611
1
$d_{\gamma(j+1)}$
$d_{\gamma(j+2)}$
. . .
$d_{\gamma(n)}$
6610-3

FIG. 66C

FIG. 66D

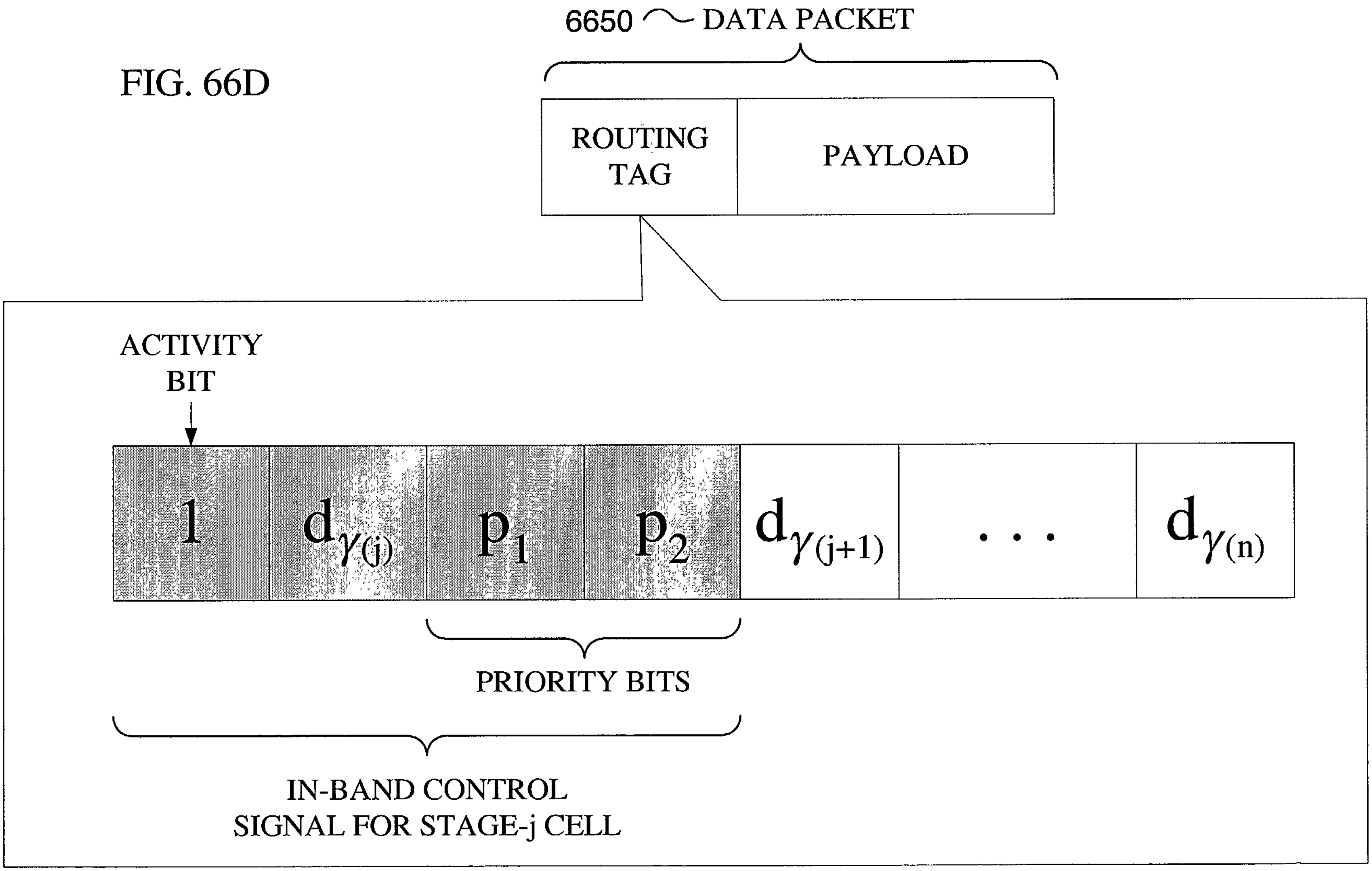

6650
DATA PACKET
ROUTING TAG
PAYLOAD
ACTIVITY BIT
1
$d_{\gamma(j)}$
p_1
p_2
$d_{\gamma(j+1)}$
. . .
$d_{\gamma(n)}$
PRIORITY BITS
IN-BAND CONTROL SIGNAL FOR STAGE-j CELL

FIG. 67A

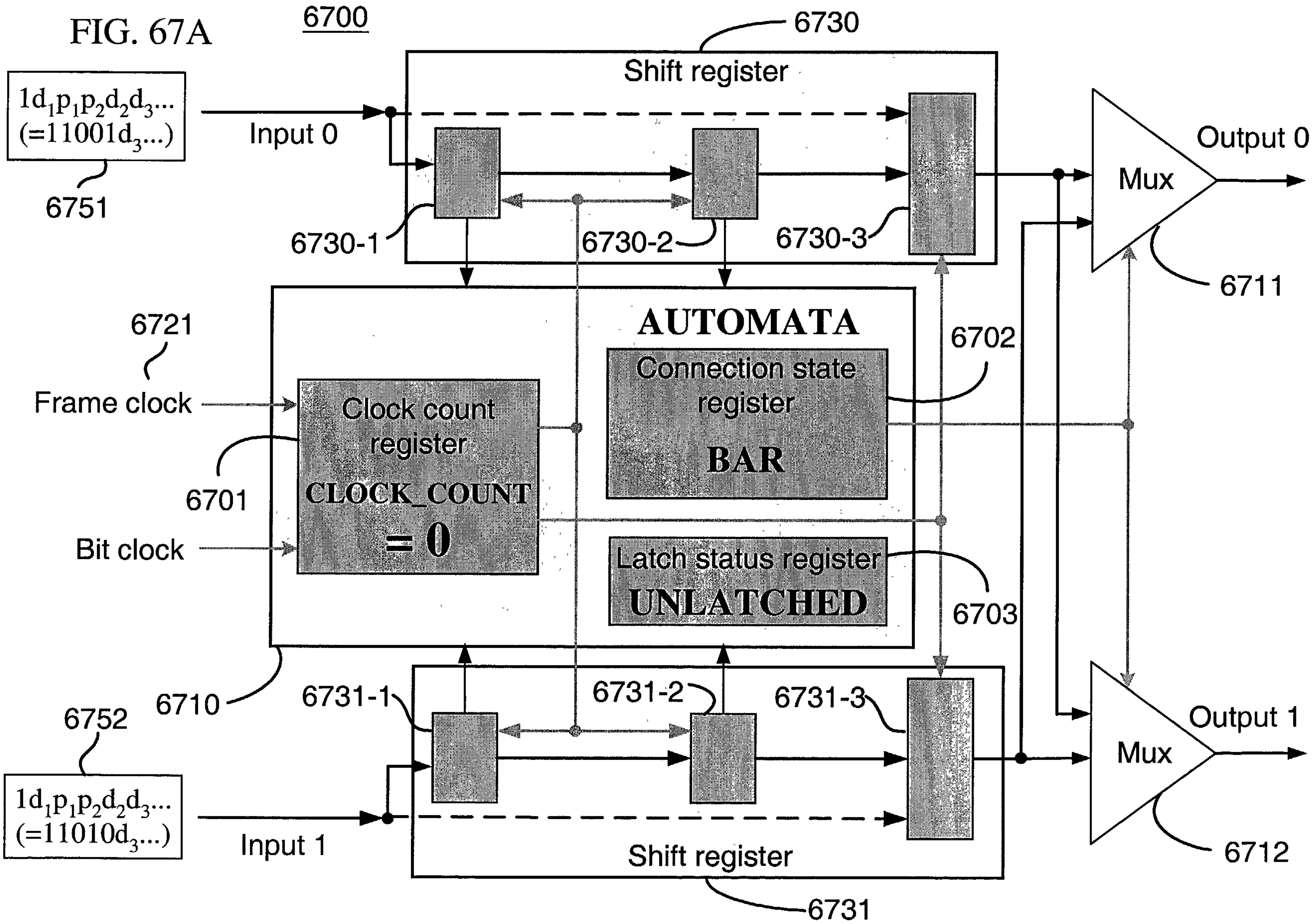

6700
6730
Shift register
$1d_1p_1p_2d_2d_3$...
(=11001d_3...)
6751
Input 0
6730-1
6730-2
6730-3
Output 0
Mux
6711
AUTOMATA
6721
Frame clock
Clock count register
CLOCK_COUNT
= 0
6701
Bit clock
Connection state register
BAR
6702
Latch status register
UNLATCHED
6703
6710
6752
$1d_1p_1p_2d_2d_3$...
(=11010d_3...)
Input 1
6731-1
6731-2
6731-3
Output 1
Mux
6712
Shift register
6731

FIG. 67B

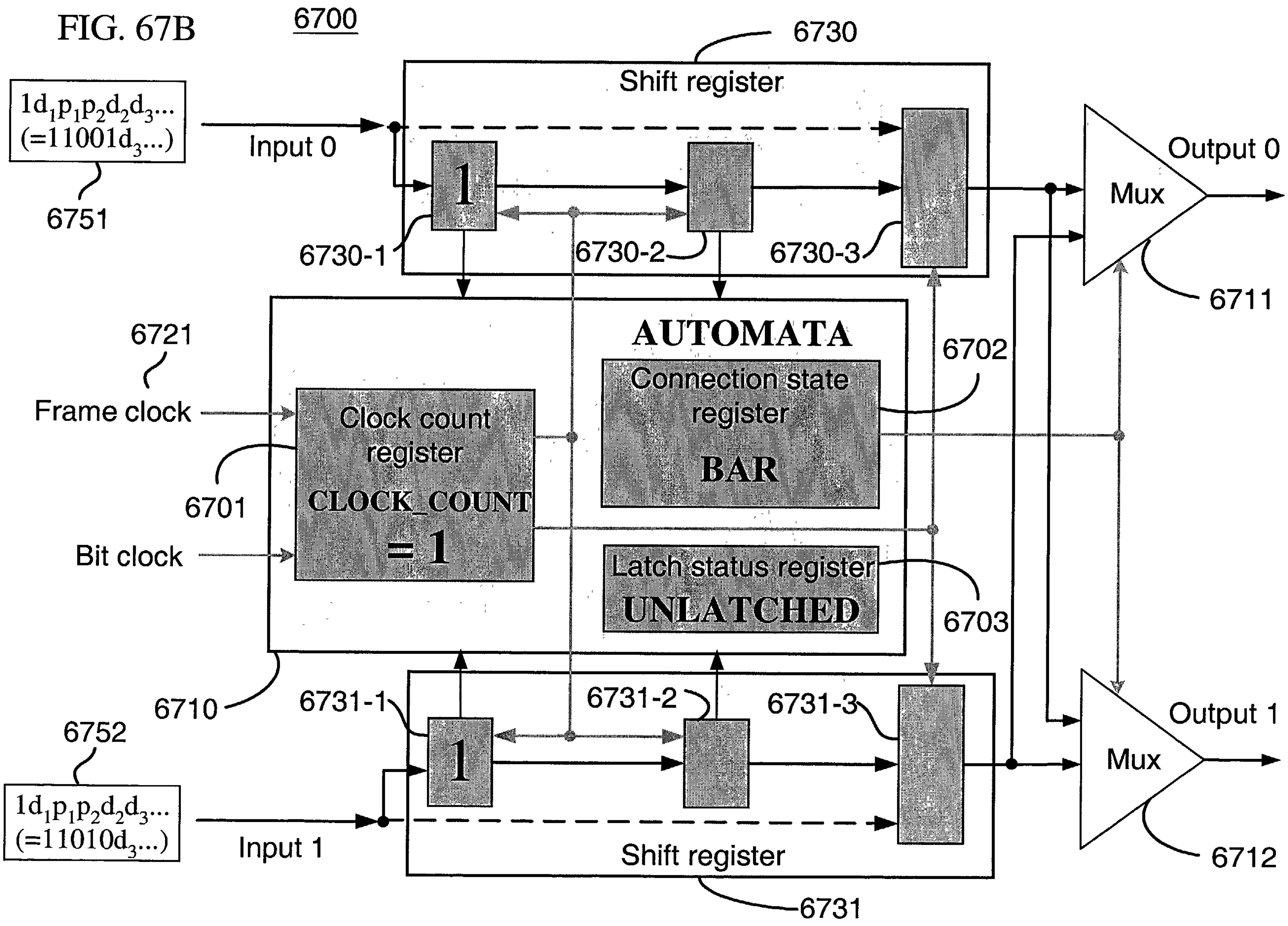

6700
6730
Shift register
$1d_1p_1p_2d_2d_3$...
(=11001d_3...)
6751
Input 0
1
6730-1
6730-2
6730-3
Mux
Output 0
6711
6721
Frame clock
AUTOMATA
Clock count register
CLOCK_COUNT
= 1
6701
Connection state register
BAR
6702
Bit clock
Latch status register
UNLATCHED
6703
6710
6752
6731-1
6731-2
6731-3
Output 1
Mux
$1d_1p_1p_2d_2d_3$...
(=11010d_3...)
Input 1
Shift register
6731
6712

FIG. 67C

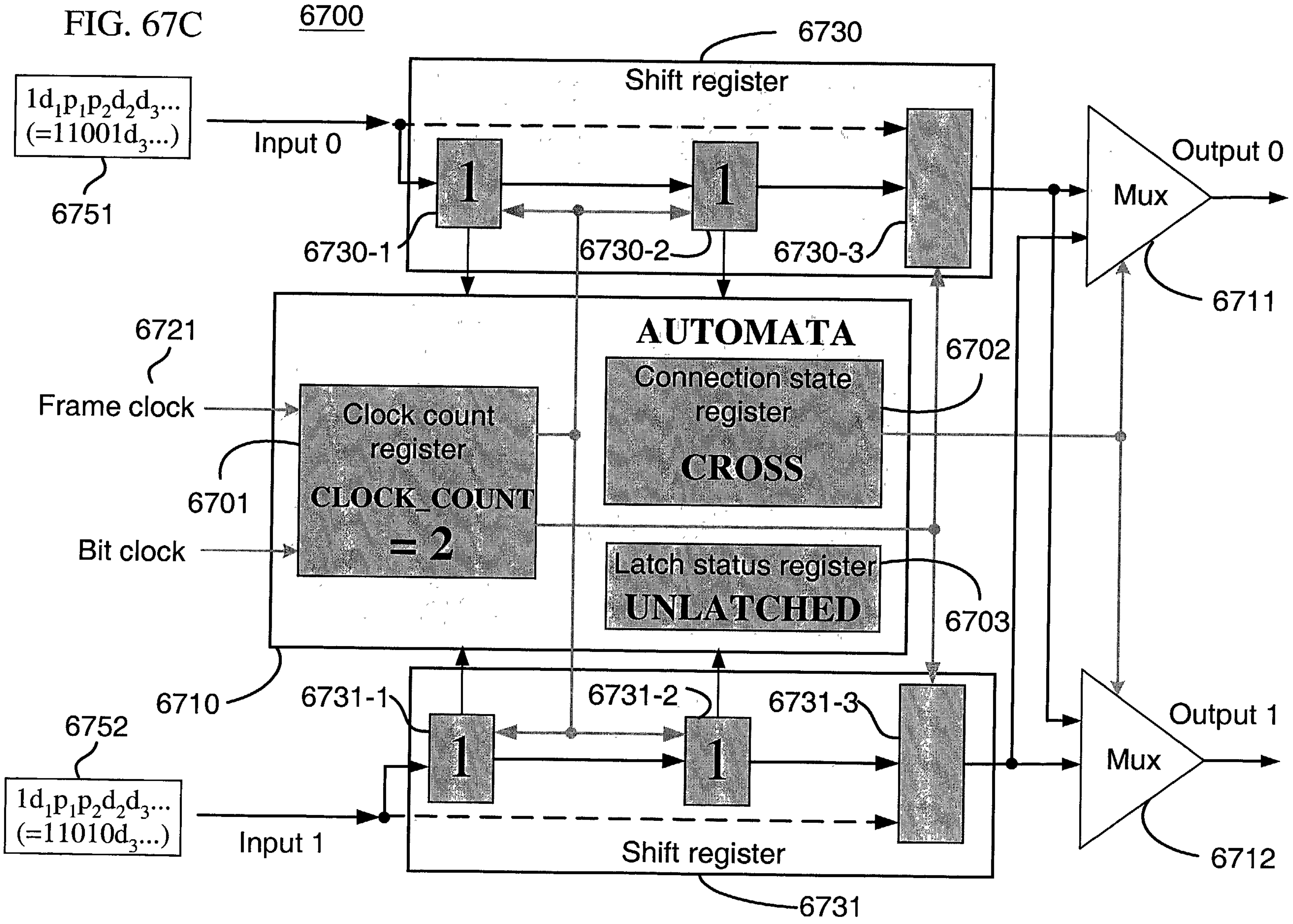

6700
6730
Shift register
$1d_1p_1p_2d_2d_3$...
$(=11001d_3...)$
6751
Input 0
1
1
6730-1
6730-2
6730-3
Output 0
Mux
6711
AUTOMATA
6721
Frame clock
Clock count register
CLOCK_COUNT
= 2
6701
Bit clock
Connection state register
CROSS
6702
Latch status register
UNLATCHED
6703
6710
6731-1
6731-2
6731-3
1
1
Output 1
Mux
6712
6752
$1d_1p_1p_2d_2d_3$...
$(=11010d_3...)$
Input 1
Shift register
6731

FIG. 67D

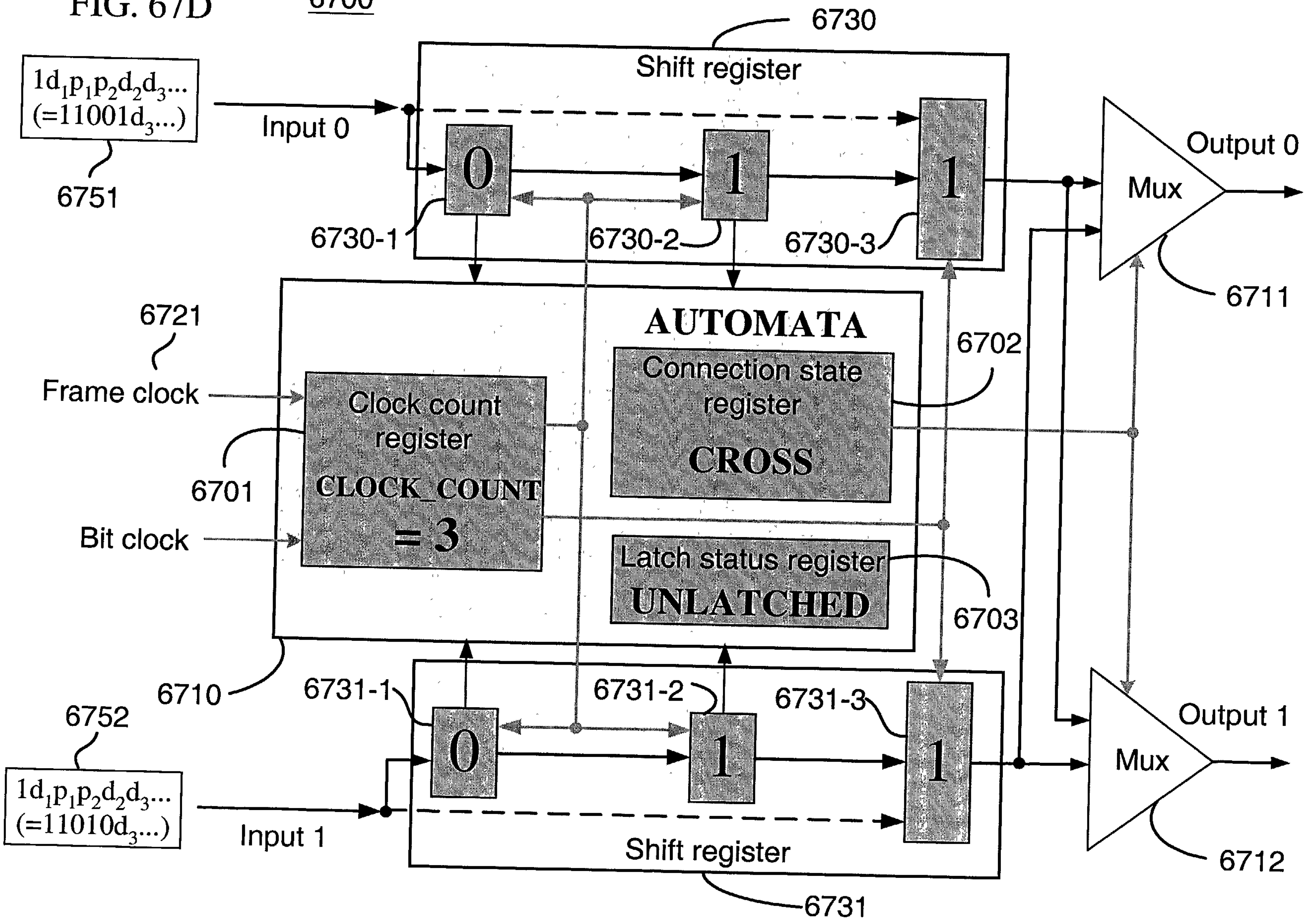

6700
$1d_1p_1p_2d_2d_3...$
$(=11001d_3...)$
6751
Input 0
6730
Shift register
0
1
1
6730-1
6730-2
6730-3
Output 0
Mux
6711
6721
Frame clock
6701
Bit clock
AUTOMATA
Clock count register
CLOCK_COUNT = 3
Connection state register
CROSS
6702
Latch status register
UNLATCHED
6703
6710
6752
$1d_1p_1p_2d_2d_3...$
$(=11010d_3...)$
Input 1
6731-1
6731-2
6731-3
0
1
1
Shift register
6731
Output 1
Mux
6712

FIG. 67E

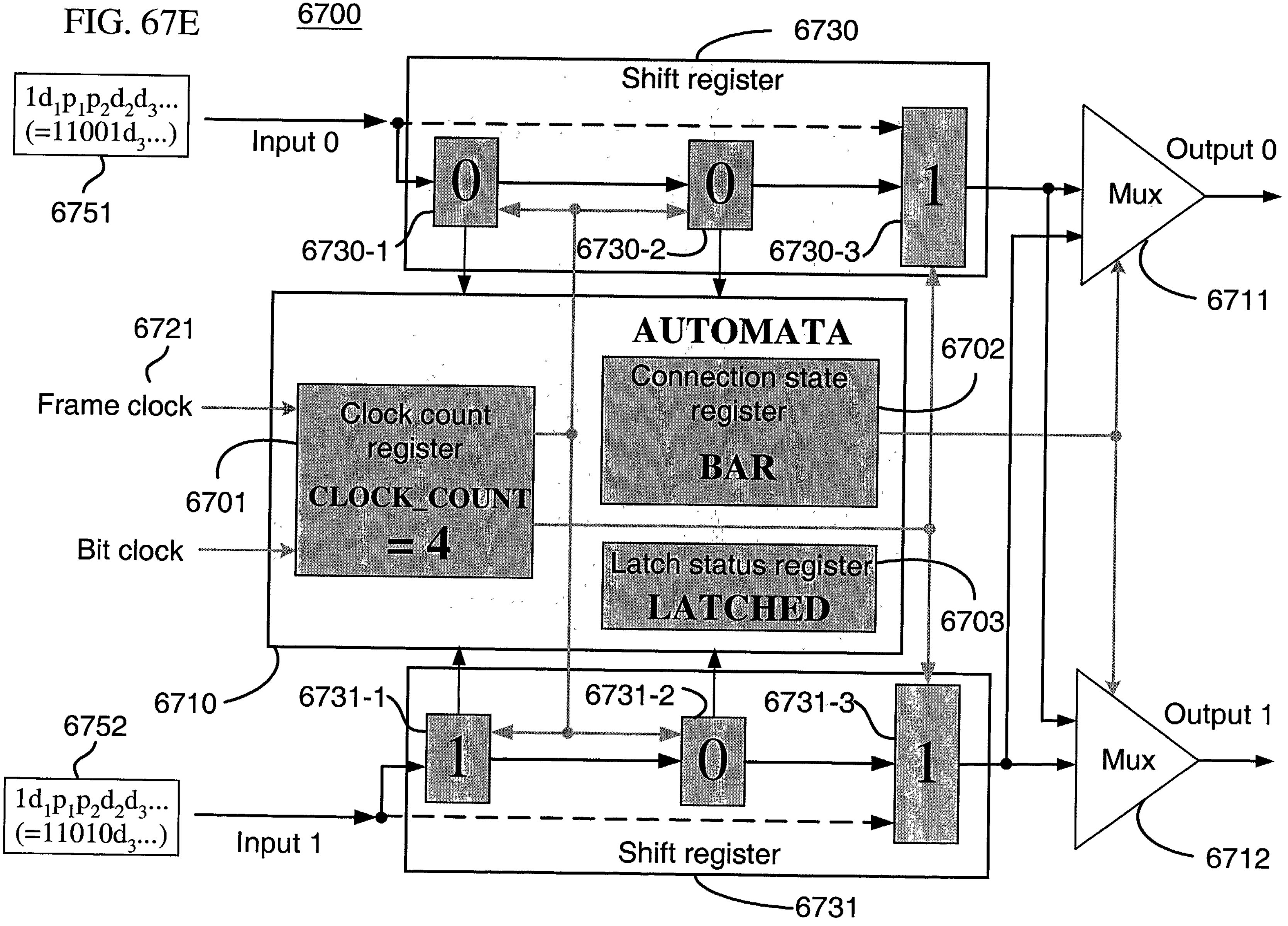
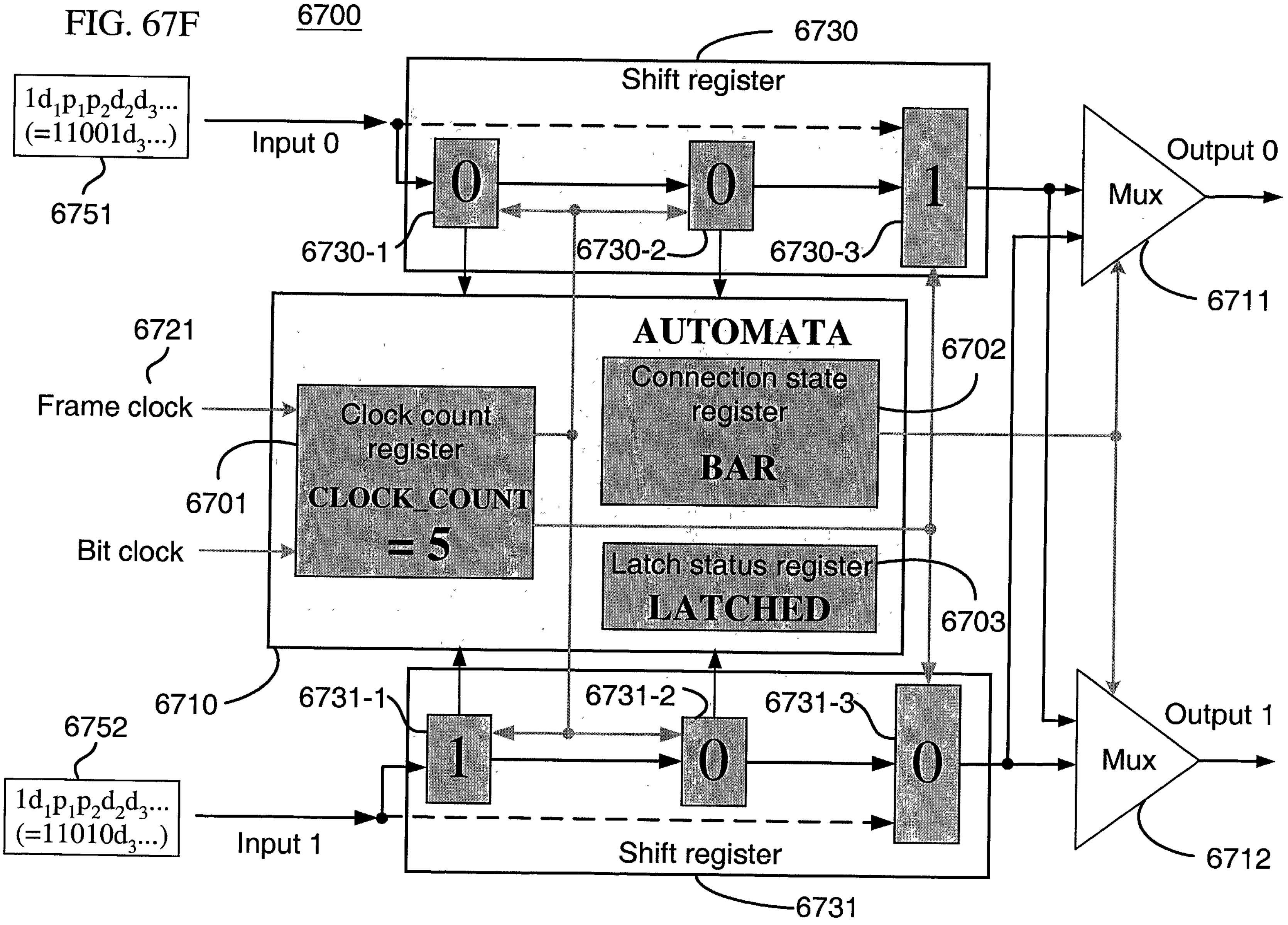

6700
6730
Shift register
$1d_1p_1p_2d_2d_3$...
(=11001d_3...)
Input 0
6751
0
0
1
6730-1
6730-2
6730-3
Mux
Output 0
6711
6721
Frame clock
6701
Bit clock
AUTOMATA
Clock count register
CLOCK_COUNT
= 4
Connection state register
BAR
6702
Latch status register
LATCHED
6703
6710
6752
$1d_1p_1p_2d_2d_3$...
(=11010d_3...)
Input 1
6731-1
6731-2
6731-3
1
0
1
Mux
Output 1
6712
Shift register
6731

FIG. 67F


6700
6730
Shift register
$1d_1p_1p_2d_2d_3...$
$(=11001d_3...)$
6751
Input 0
0
0
1
6730-1
6730-2
6730-3
Mux
Output 0
6711
AUTOMATA
6721
Frame clock
Clock count register
CLOCK_COUNT = 5
6701
Bit clock
Connection state register
BAR
6702
Latch status register
LATCHED
6703
6710
6752
$1d_1p_1p_2d_2d_3...$
$(=11010d_3...)$
Input 1
6731-1
6731-2
6731-3
1
0
0
Shift register
6731
Mux
Output 1
6712

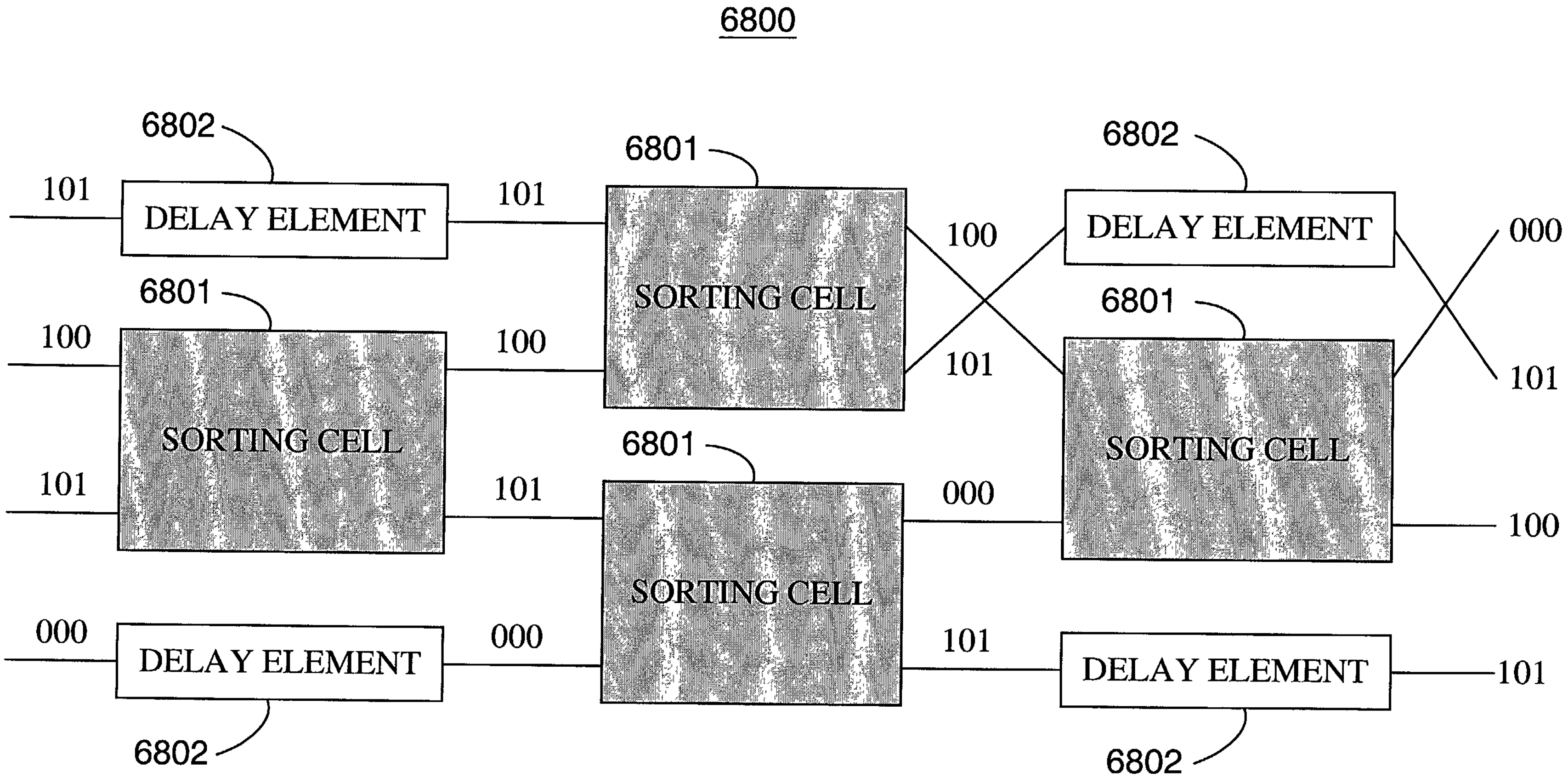
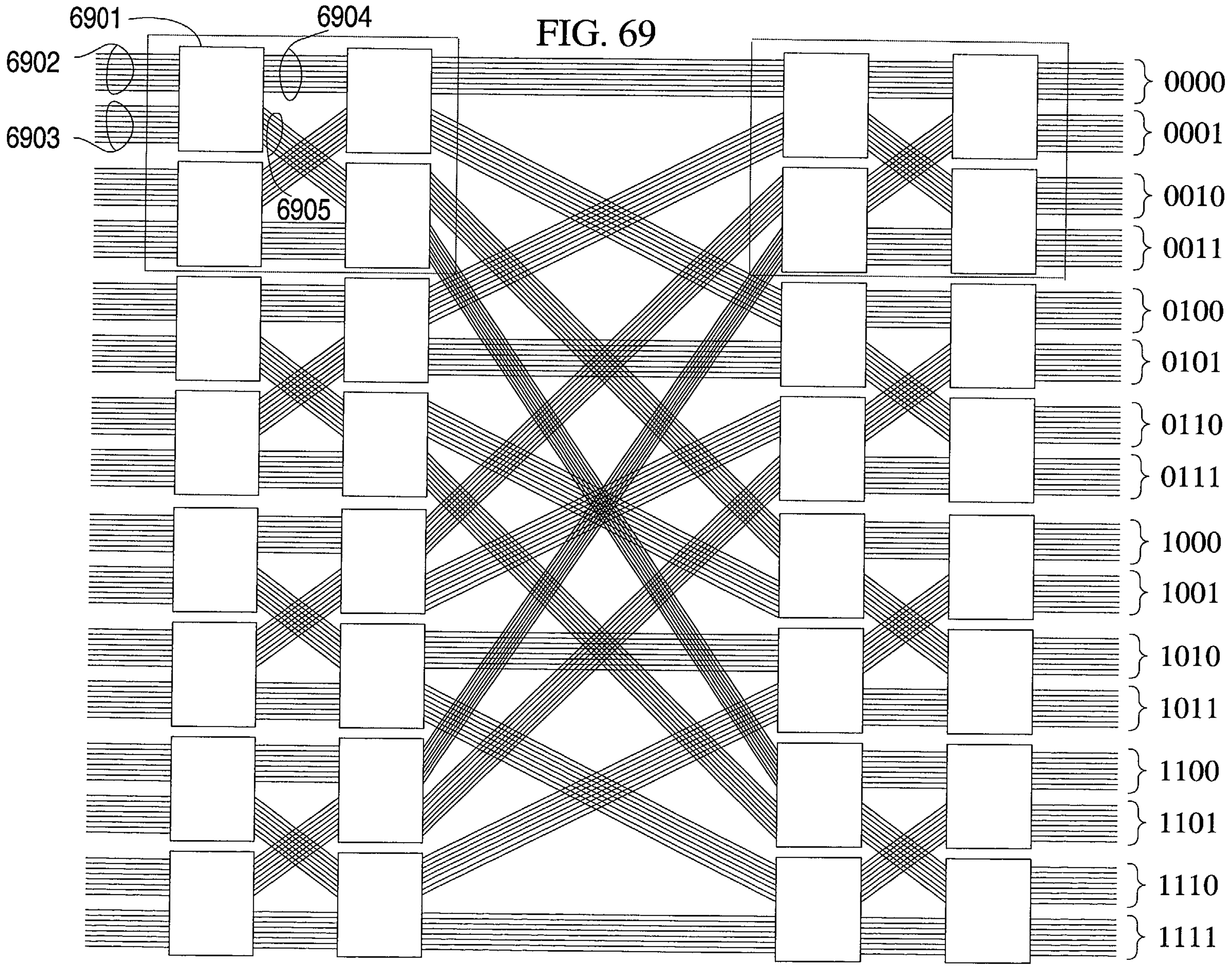

6800
6802
6801
6802
6801
6801
6802
6801
6802
DELAY ELEMENT
SORTING CELL
DELAY ELEMENT
SORTING CELL
SORTING CELL
DELAY ELEMENT
SORTING CELL
DELAY ELEMENT
101
100
101
000
101
100
101
000
100
101
000
101
000
101
100
101

FIG. 68

FIG. 69


6901
6902
6903
6904
6905
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111

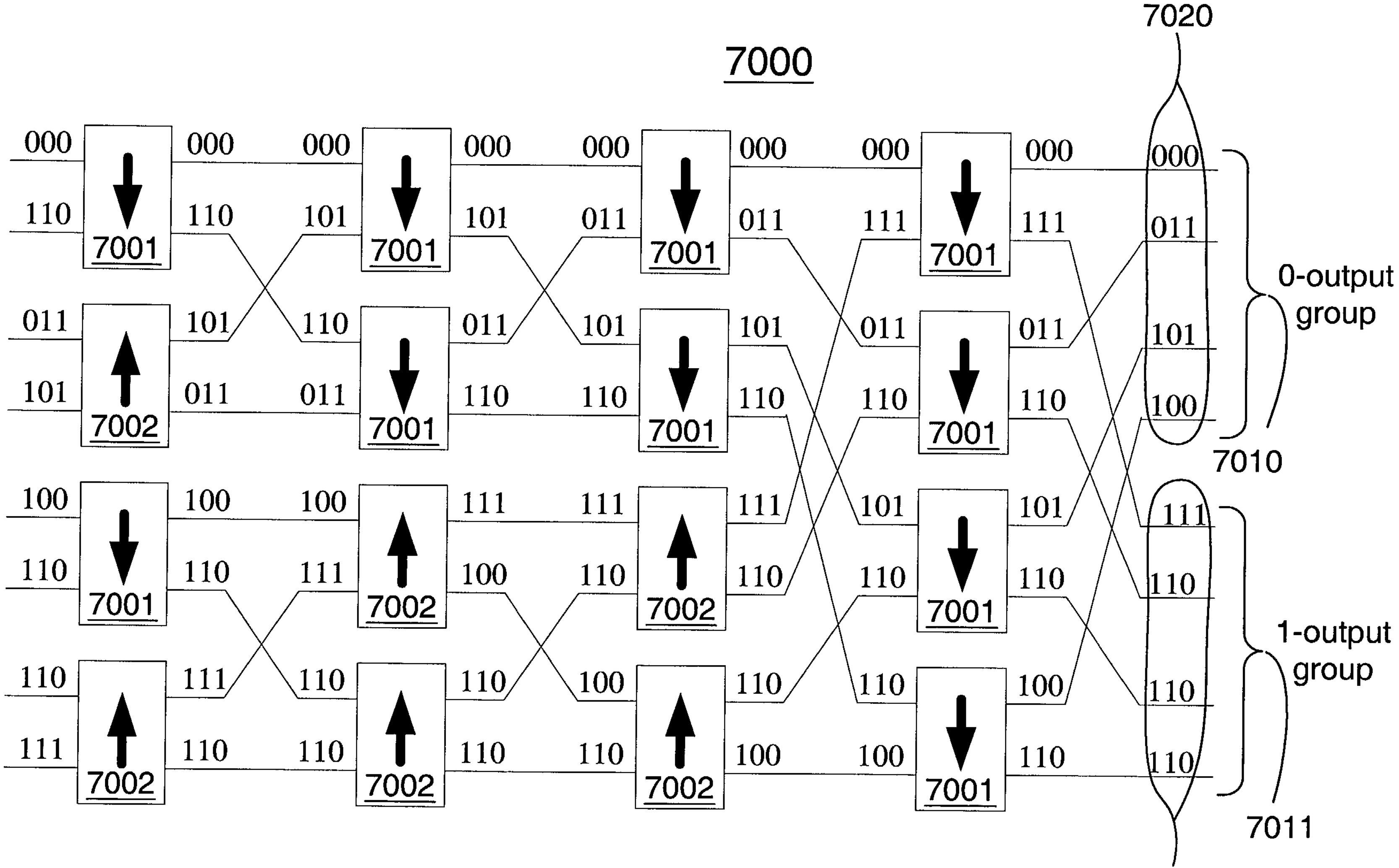

7000
7020
000
110
011
101
100
110
110
111
7001
7002
7001
7002
000
110
101
011
100
110
111
110
000
101
110
011
100
111
110
110
7001
7001
7002
7002
000
101
011
110
111
100
110
110
000
011
101
110
111
110
100
110
7001
7001
7002
7002
000
011
101
110
111
110
110
100
000
111
011
110
101
110
110
100
7001
7001
7001
7001
000
111
011
110
101
110
100
110
000
011
101
100
111
110
110
110
0-output group
7010
1-output group
7011
7021

FIG. 70A

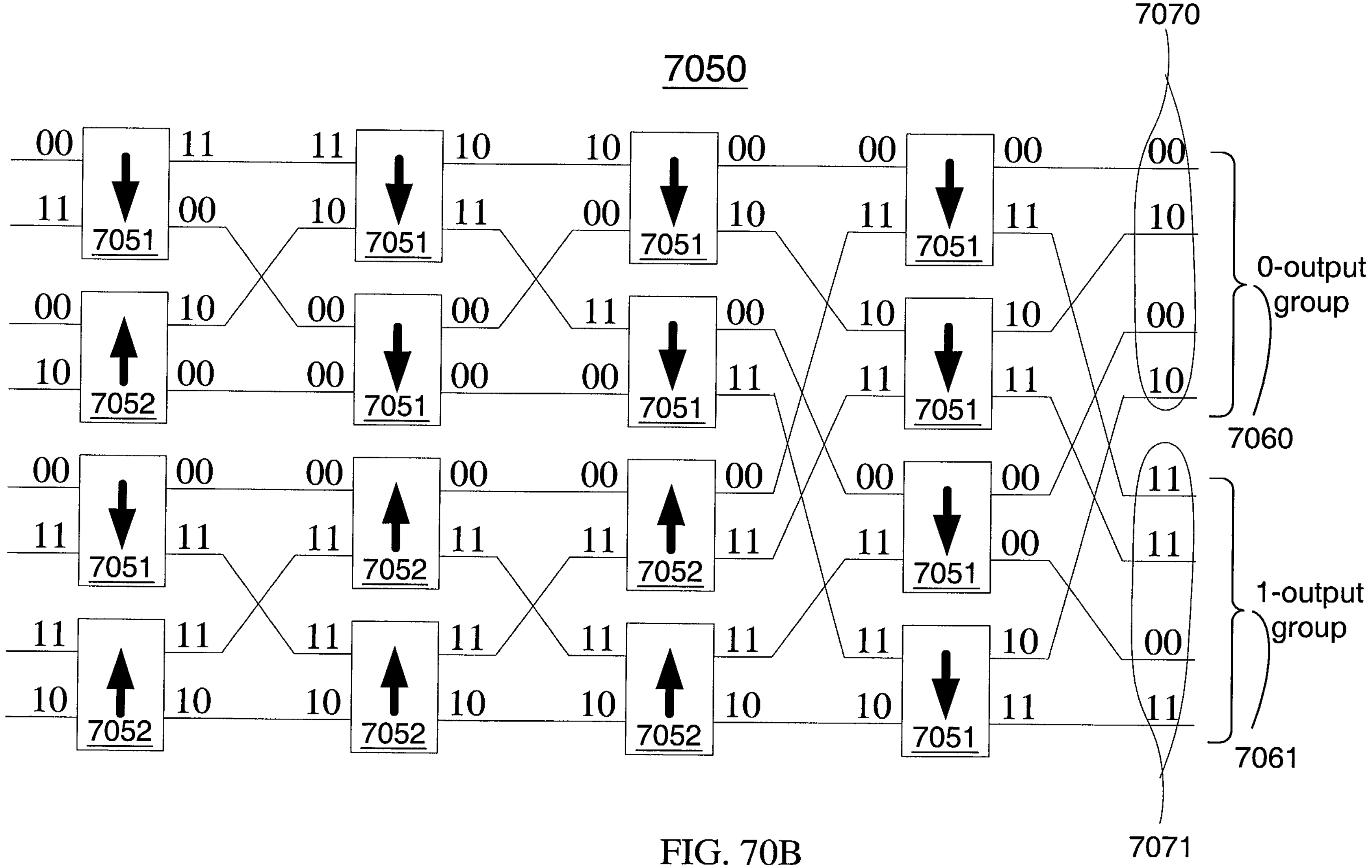

7050
7070
7051
7052
00
11
10
0-output group
7060
1-output group
7061
7071

FIG. 70B

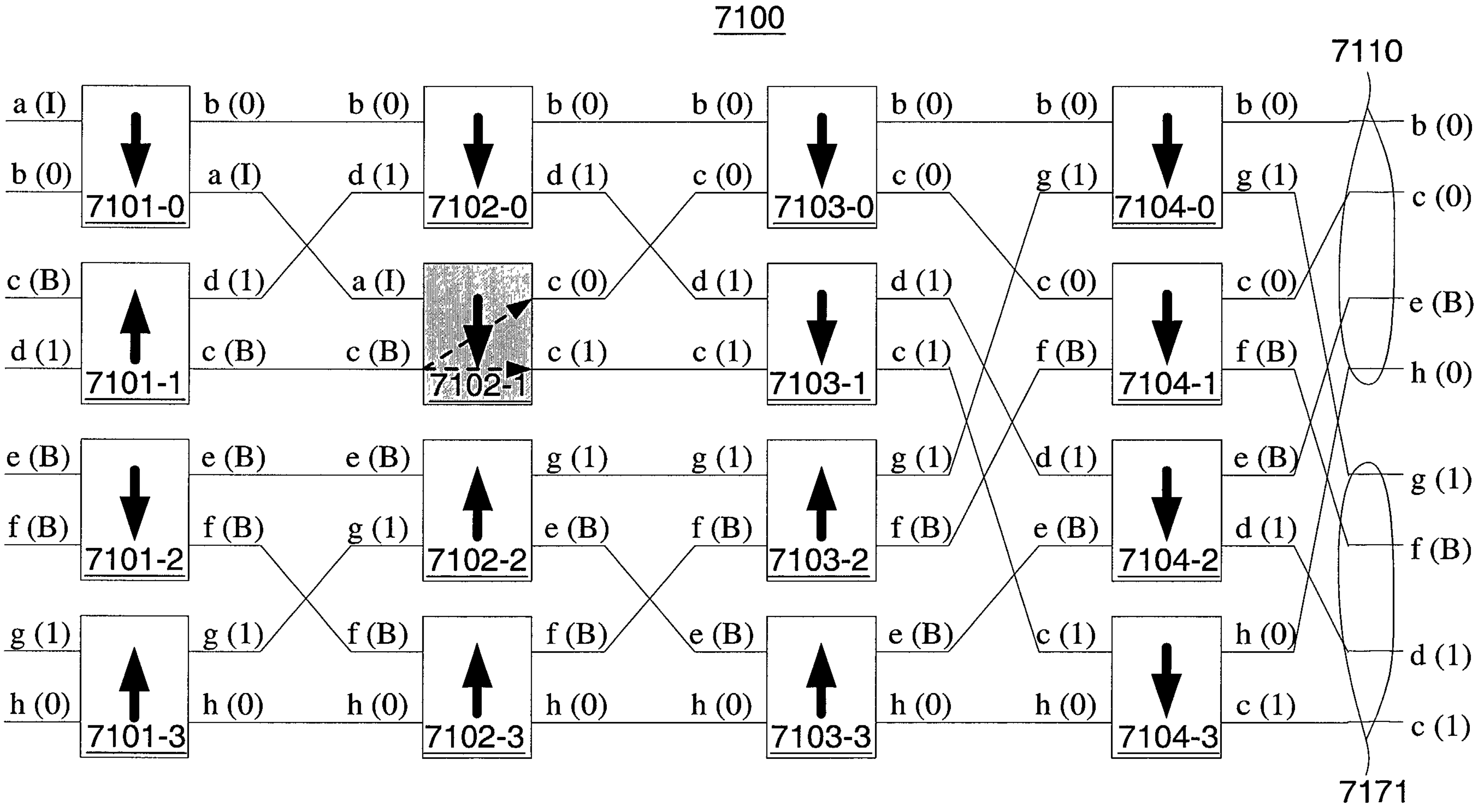

7100
7110
7171
a (I)
b (0)
c (B)
d (1)
e (B)
f (B)
g (1)
h (0)
7101-0
7101-1
7101-2
7101-3
7102-0
7102-1
7102-2
7102-3
7103-0
7103-1
7103-2
7103-3
7104-0
7104-1
7104-2
7104-3
c (0)
c (1)
b (0)
c (0)
e (B)
h (0)
g (1)
f (B)
d (1)
c (1)

FIG. 71A

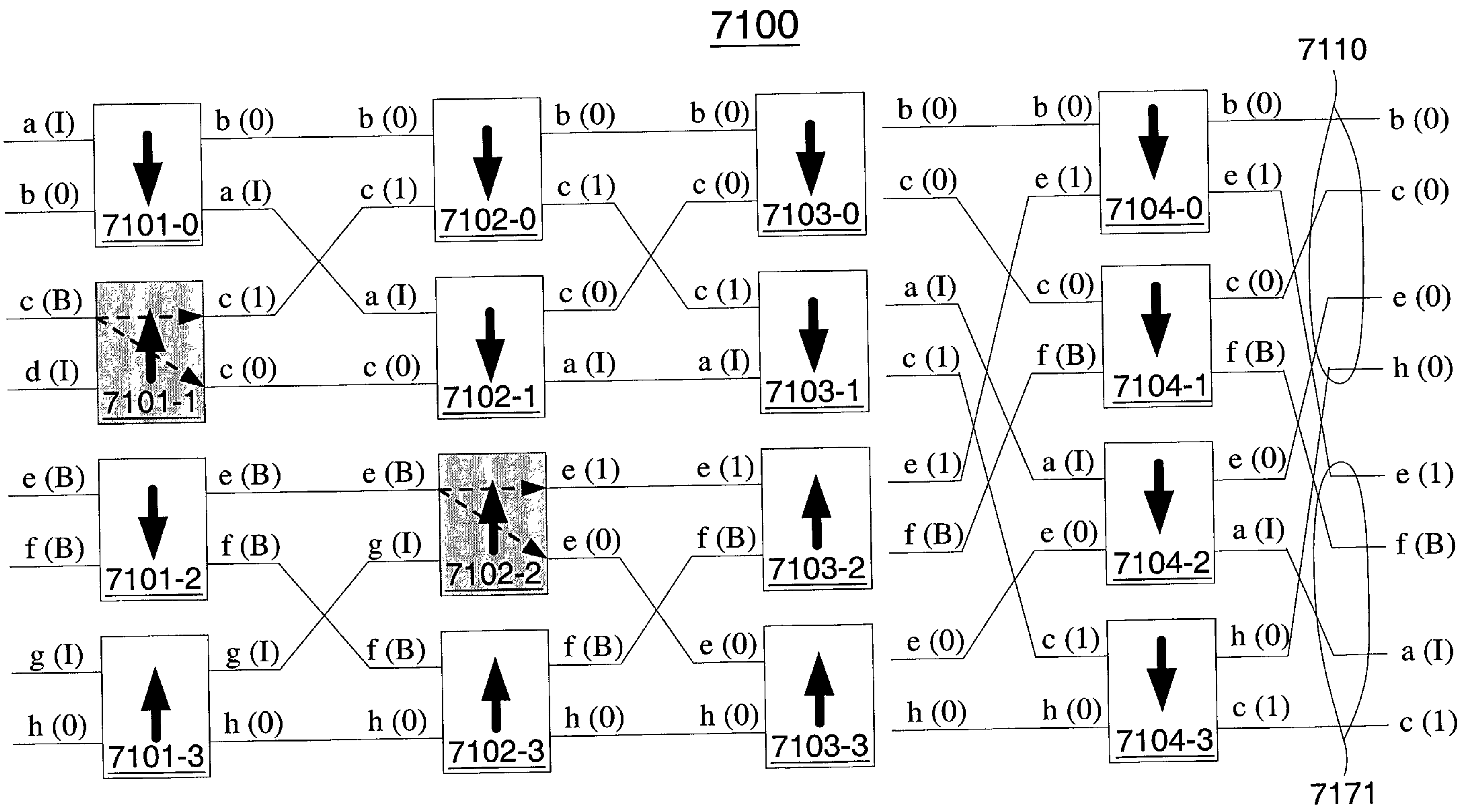

7100
7110
a (I)
b (0)
c (B)
d (I)
e (B)
f (B)
g (I)
h (0)
7101-0
7101-1
7101-2
7101-3
b (0)
a (I)
c (1)
c (0)
e (B)
f (B)
g (I)
h (0)
b (0)
c (1)
a (I)
c (0)
e (B)
g (I)
f (B)
h (0)
7102-0
7102-1
7102-2
7102-3
b (0)
c (1)
c (0)
a (I)
e (1)
e (0)
f (B)
h (0)
b (0)
c (0)
c (1)
a (I)
e (1)
f (B)
e (0)
h (0)
7103-0
7103-1
7103-2
7103-3
b (0)
c (0)
a (I)
c (1)
e (1)
f (B)
e (0)
h (0)
b (0)
e (1)
c (0)
f (B)
a (I)
e (0)
c (1)
h (0)
7104-0
7104-1
7104-2
7104-3
b (0)
e (1)
c (0)
f (B)
e (0)
a (I)
h (0)
c (1)
b (0)
c (0)
e (0)
h (0)
e (1)
f (B)
a (I)
c (1)
7171

FIG. 71B

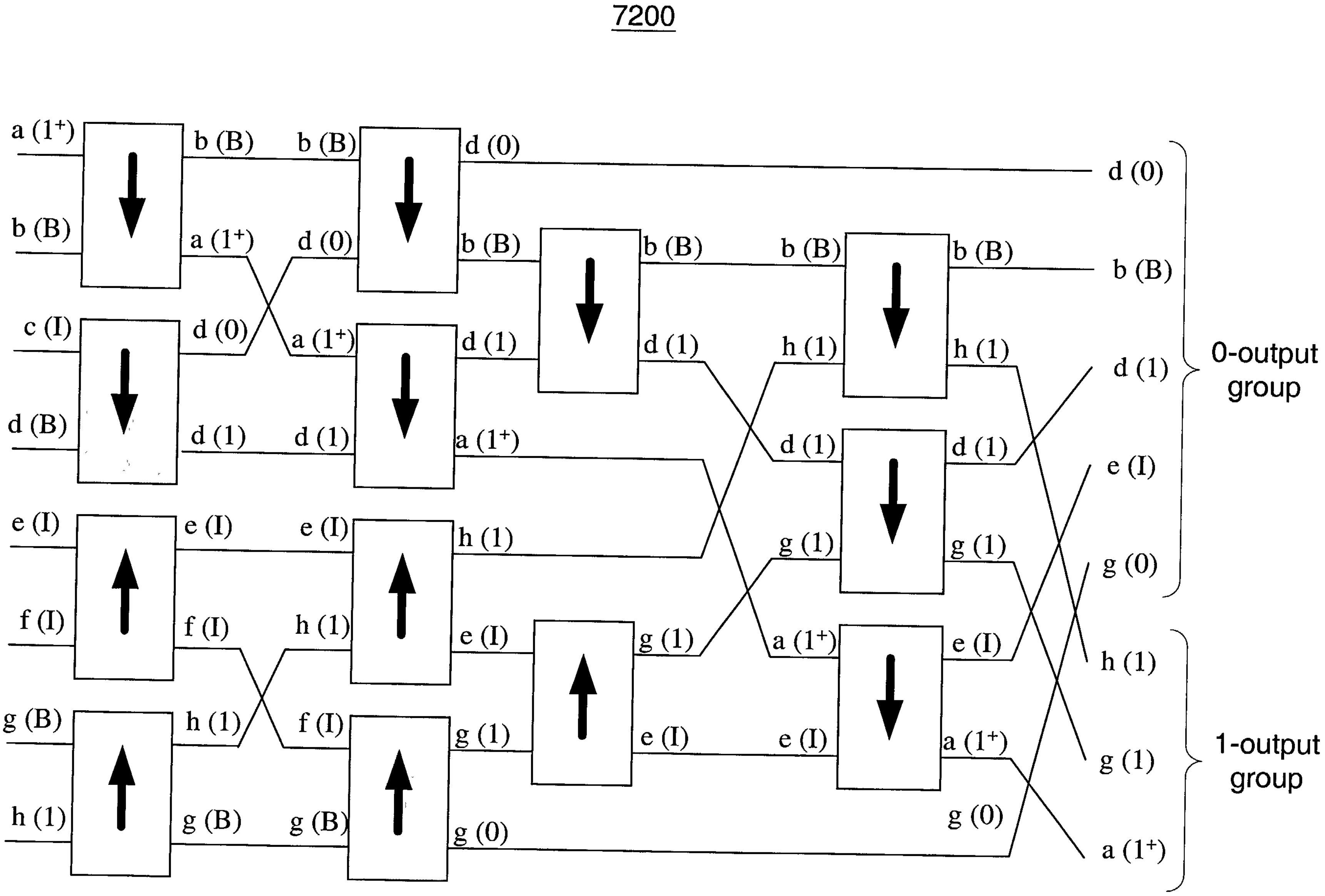
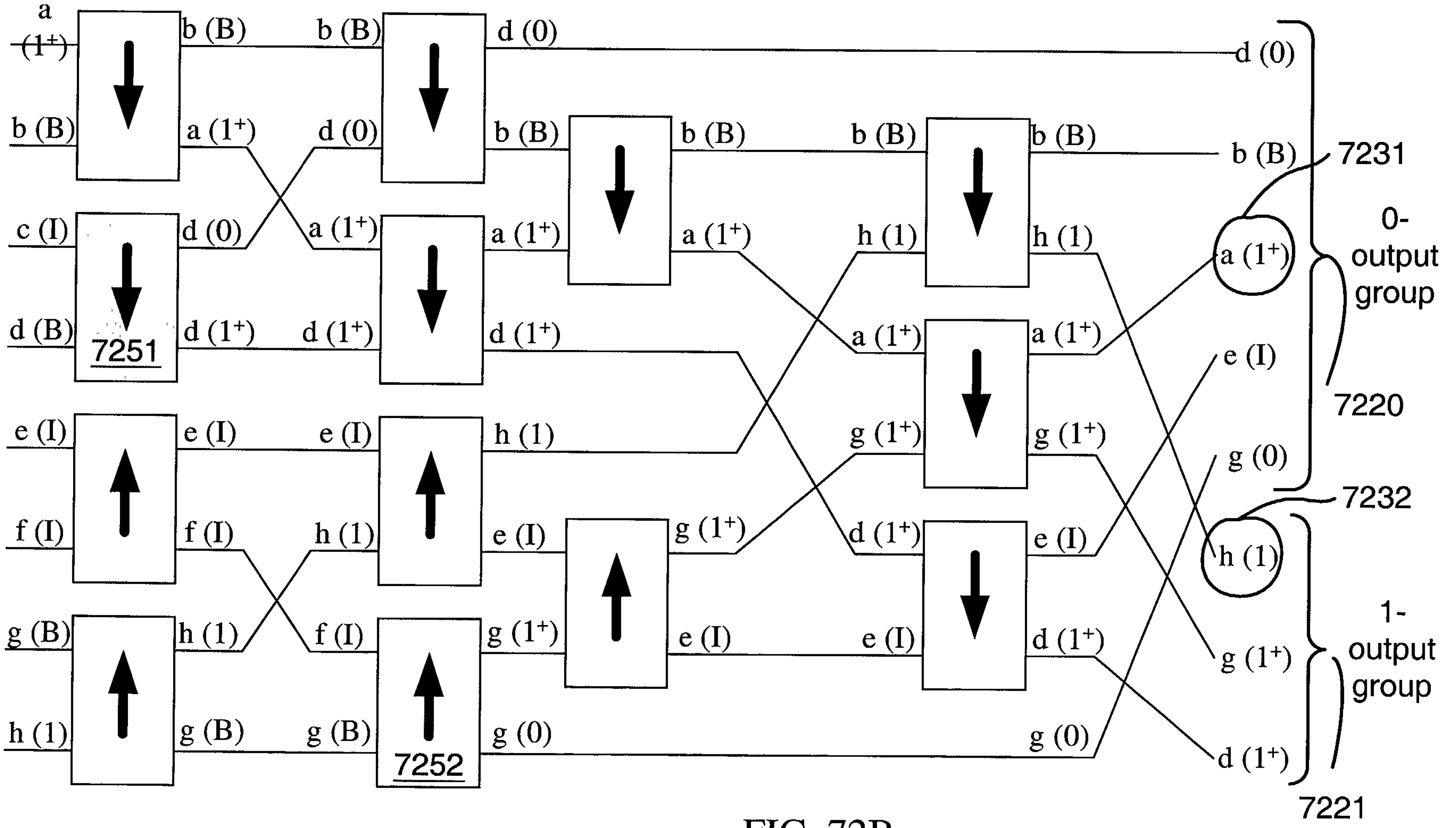

7200
a (1+)
b (B)
c (I)
d (B)
e (I)
f (I)
g (B)
h (1)
b (B)
a (1+)
d (0)
d (1)
e (I)
f (I)
h (1)
g (B)
b (B)
d (0)
a (1+)
d (1)
e (I)
h (1)
f (I)
g (B)
d (0)
b (B)
d (1)
a (1+)
h (1)
e (I)
g (1)
g (0)
b (B)
d (1)
g (1)
e (I)
b (B)
h (1)
d (1)
g (1)
a (1+)
e (I)
b (B)
h (1)
d (1)
g (1)
e (I)
a (1+)
g (0)
d (0)
b (B)
d (1)
e (I)
g (0)
h (1)
g (1)
a (1+)
0-output group
1-output group

FIG. 72A

7200



a (1+)
b (B)
c (I)
d (B)
e (I)
f (I)
g (B)
h (1)
b (B)
a (1+)
d (0)
d (1+)
e (I)
f (I)
h (1)
g (B)
7251
b (B)
d (0)
a (1+)
d (1+)
e (I)
h (1)
f (I)
g (B)
d (0)
b (B)
a (1+)
d (1+)
h (1)
e (I)
g (1+)
g (0)
7252
b (B)
a (1+)
g (1+)
e (I)
b (B)
h (1)
a (1+)
g (1+)
d (1+)
e (I)
b (B)
h (1)
a (1+)
g (1+)
e (I)
d (1+)
g (0)
d (0)
b (B)
a (1+)
e (I)
g (0)
h (1)
g (1+)
d (1+)
7231
0-
output
group
7220
7232
1-
output
group
7221

FIG. 72B

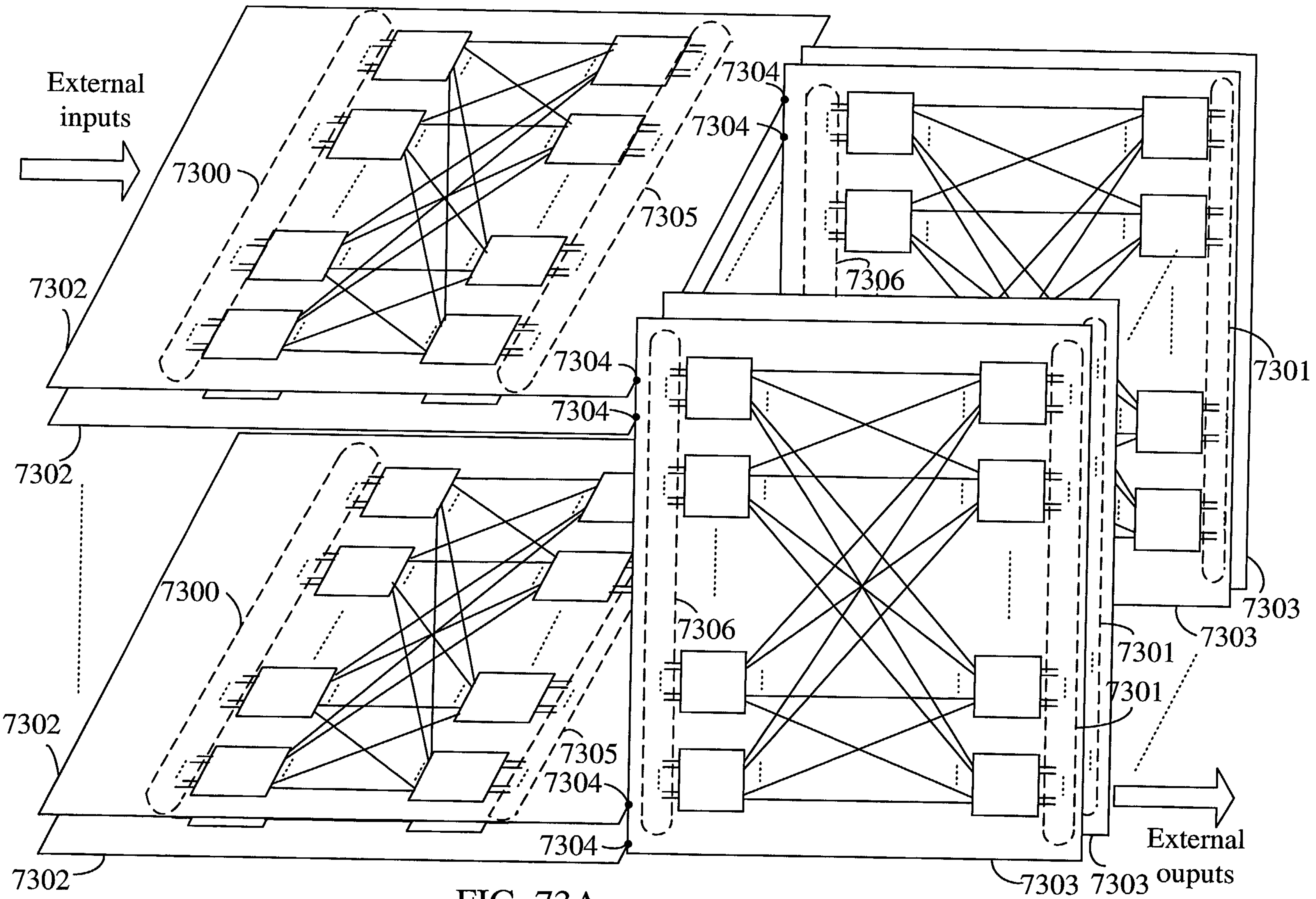
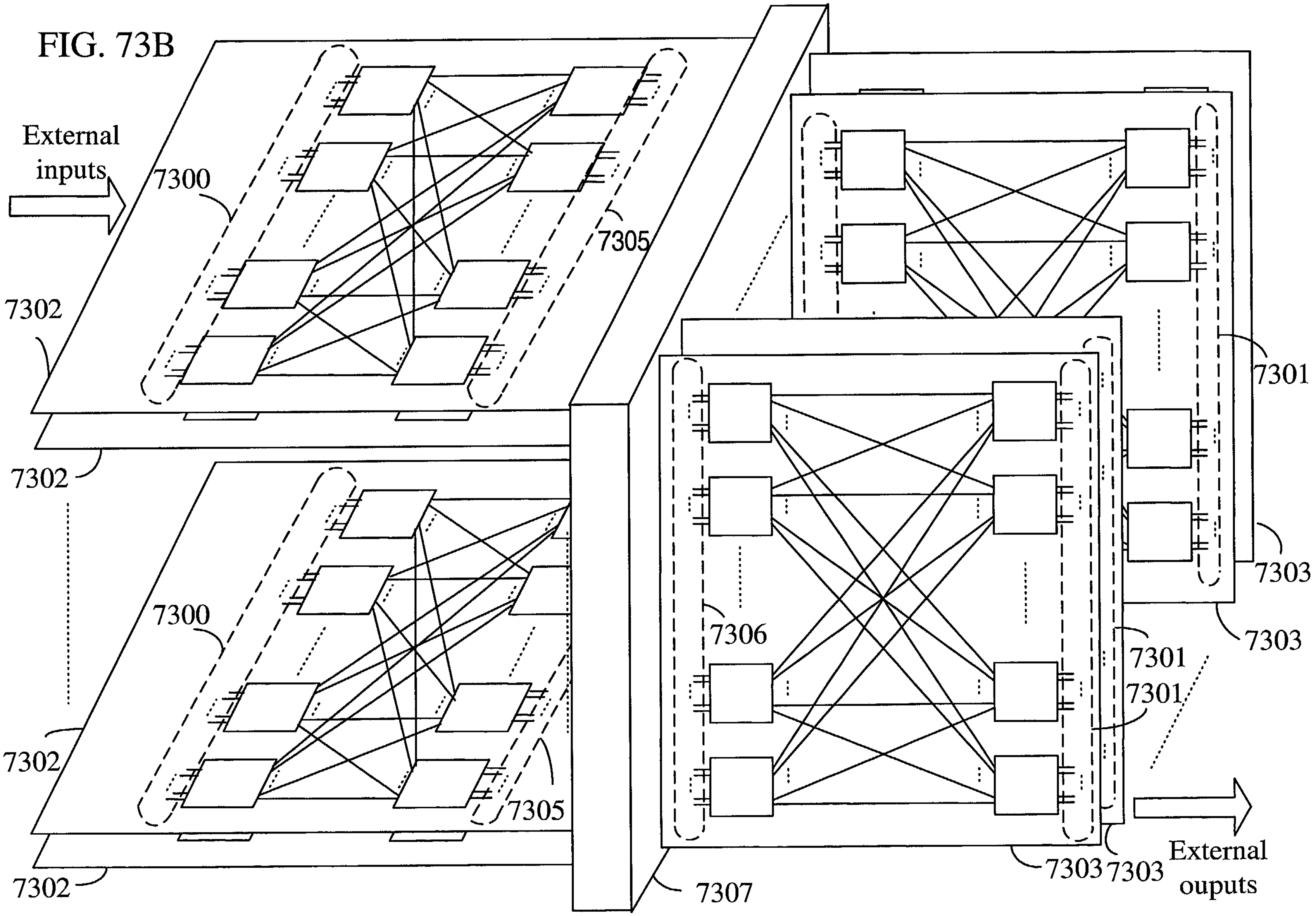

External
inputs
7300
7305
7302
7304
7304
7304
7304
7302
7300
7302
7305
7304
7304
7302
7306
7306
7301
7303
7303
7301
7301
7303
7303
External
ouputs

FIG. 73A

FIG. 73B


External
inputs
7300
7305
7302
7302
7300
7302
7305
7302
7301
7303
7306
7303
7301
7301
7307
7303
7303
External
ouputs

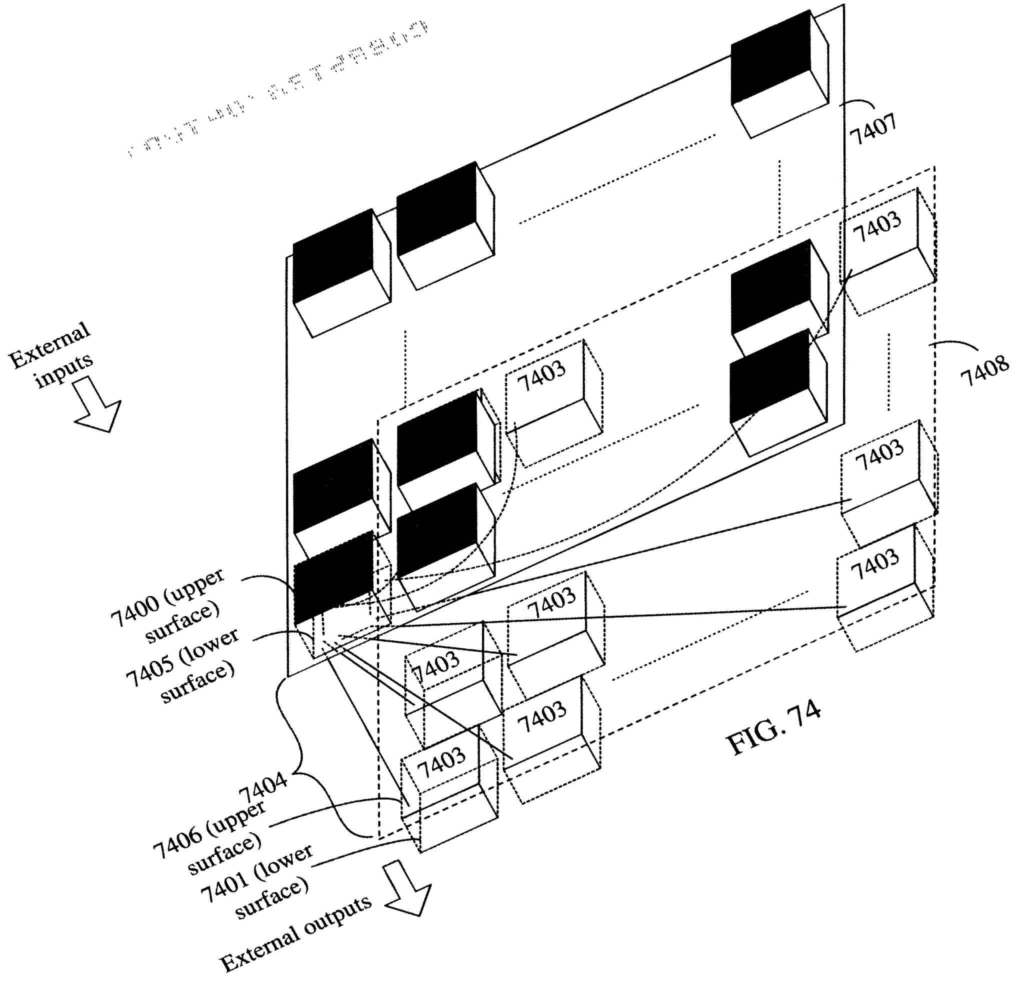

External inputs
7407
7403
7403
7408
7403
7403
7403
7403
7403
7400 (upper surface)
7405 (lower surface)
7404
7406 (upper surface)
7401 (lower surface)
External outputs

FIG. 74

FIG. 75A

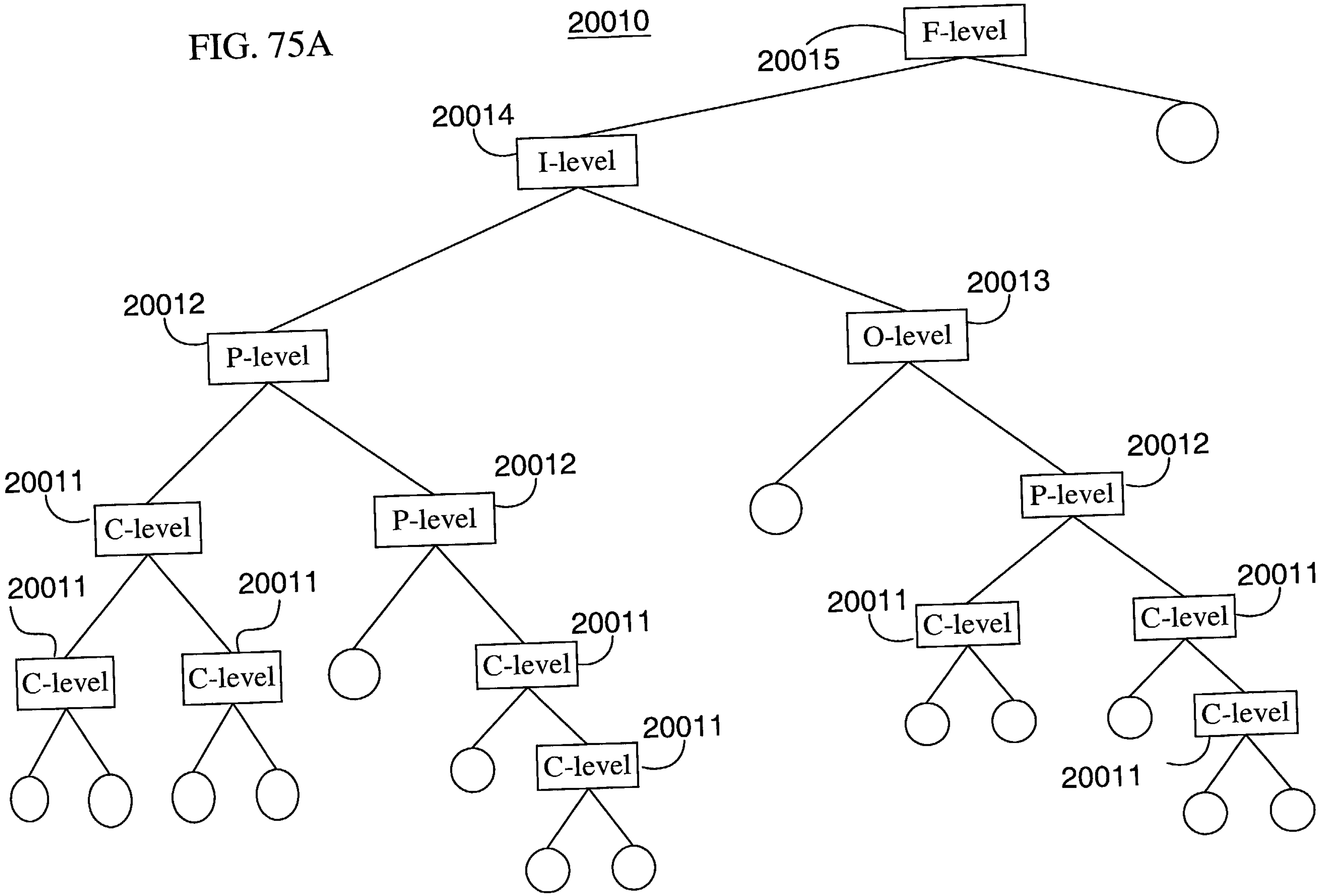

20010
F-level
20015
I-level
20014
P-level
20012
O-level
20013
C-level
20011
P-level
20012
P-level
20012
C-level
20011
C-level
20011
C-level
20011
C-level
20011
C-level
20011
C-level
20011
C-level
20011
20011

FIG. 75B

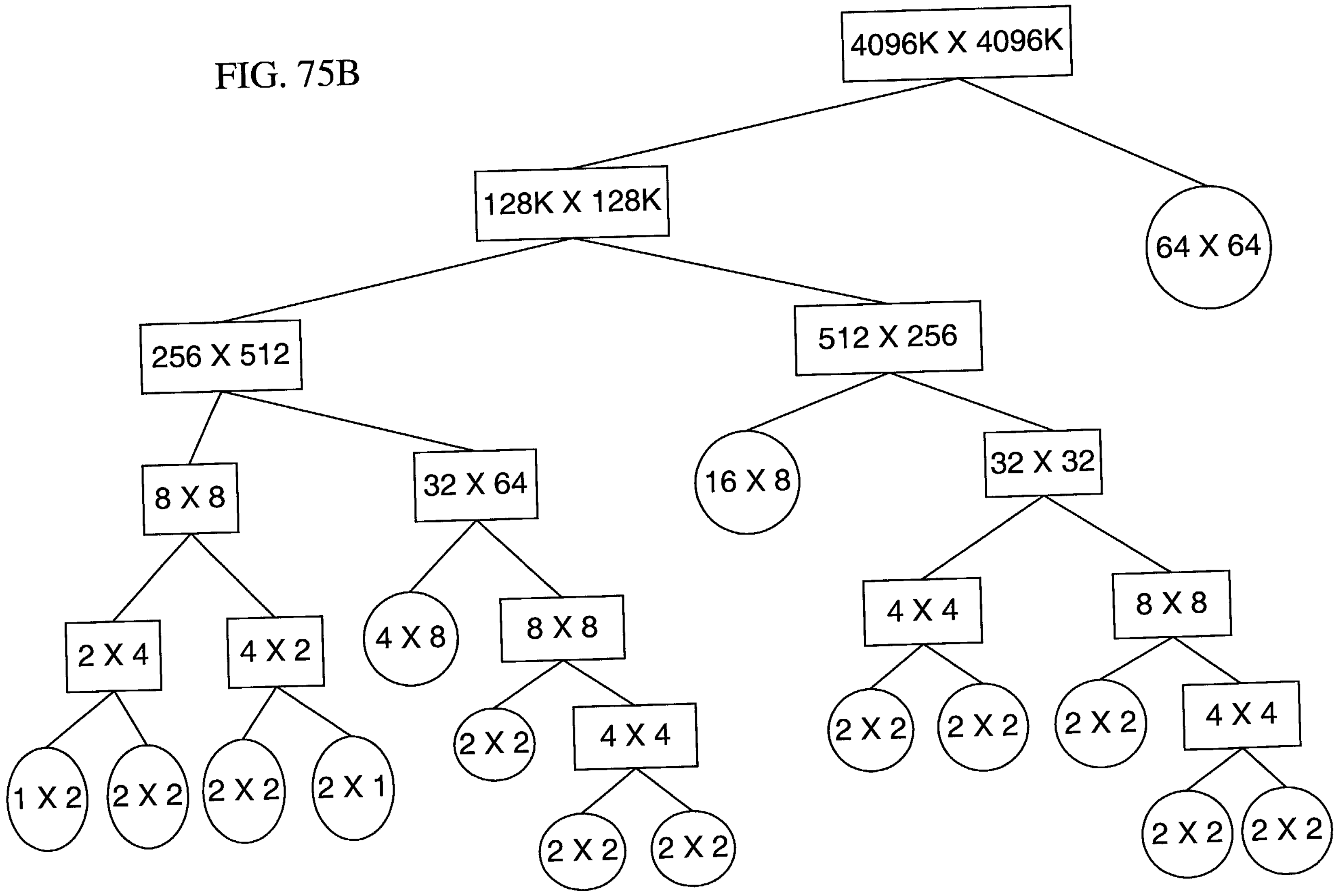
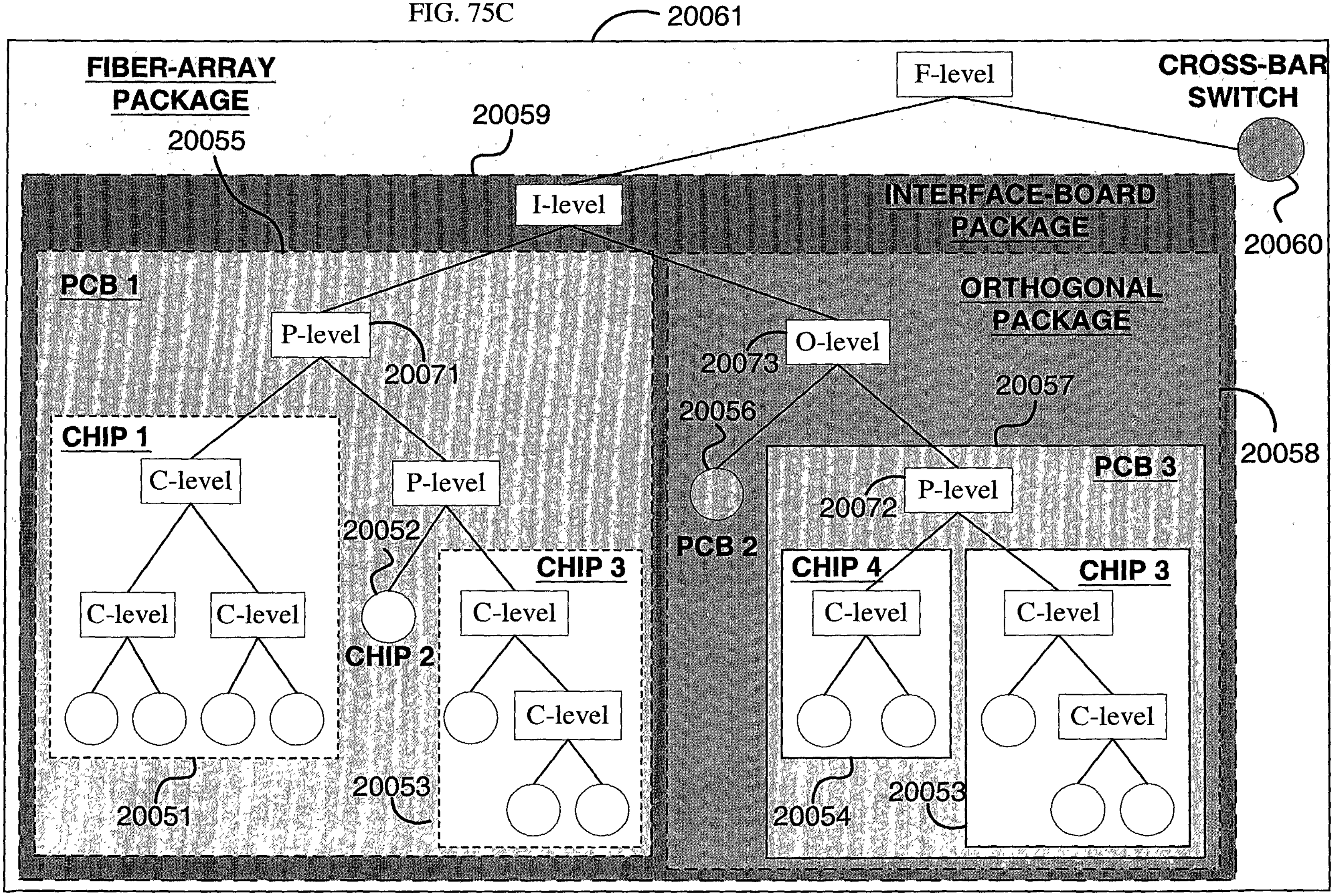

4096K X 4096K
128K X 128K
64 X 64
256 X 512
512 X 256
8 X 8
32 X 64
16 X 8
32 X 32
2 X 4
4 X 2
4 X 8
8 X 8
4 X 4
8 X 8
1 X 2
2 X 2
2 X 2
2 X 1
2 X 2
4 X 4
2 X 2
2 X 2
2 X 2
2 X 2
2 X 2
4 X 4
2 X 2
2 X 2

FIG. 75C


20061
FIBER-ARRAY PACKAGE
20055
20059
F-level
CROSS-BAR SWITCH
20060
I-level
INTERFACE-BOARD PACKAGE
PCB 1
P-level
20071
ORTHOGONAL PACKAGE
O-level
20073
20056
20057
20058
CHIP 1
C-level
C-level
C-level
20051
P-level
20052
CHIP 2
CHIP 3
C-level
C-level
20053
PCB 2
PCB 3
P-level
20072
CHIP 4
C-level
20054
CHIP 3
C-level
C-level
20053